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HENSON—INVENTOR OF THE AIRPLANE.

BY

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PRIMARY ELEMENTS.

The power-driven airplane was first invented by William Samuel Henson, engineer, of London, England. Previous persons indeed had flown glider models, and had published accounts of their structure and performance. But these craft lacked automotive power and strictly are not classed as airplanes. Henson is the original inventor of the true airplane.*

On September 29, 1842, Henson was awarded British patent No. 9478 for an airplane covering all, and more than all, the organs essential to pioneer flying. As shown in his patent its cardinal features comprise: (1) a closed-cabin body housing pilot, cargo and controls; (2) a tricycle under-carriage to taxi and take off; (3) a fixed wing for support in flight; (4) a rear horizontal rudder for steering in pitch; (5) a rear vertical rudder for steering in yaw; (6) twin pusher airscrews cord-driven by a central "steam or other proper engine."

These six broad disclosures may be called Henson's primary claims. Some are indispensable; for no avion can fly without wings and propulsive means. All six are requisite in today's landplanes; all except wheels are requisite for seaplanes. In patent law they broadly anticipate all equivalent devices later invented.

Further features are noteworthy and clearly detailed in the original specification. The engine and two rudders are controlled by the pilot; the other three parts are fixed. A fixed vertical keel cloth over the centroid promotes both stability in roll and steering in yaw. The wings

* The U. S. Official nomenclature defines the airplane as "A mechanically driven fixed-wing aircraft, heavier than air, which is supported by the dynamic reaction of the air against its wings."

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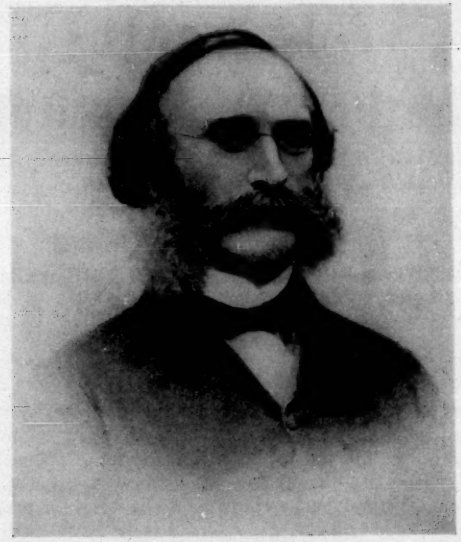
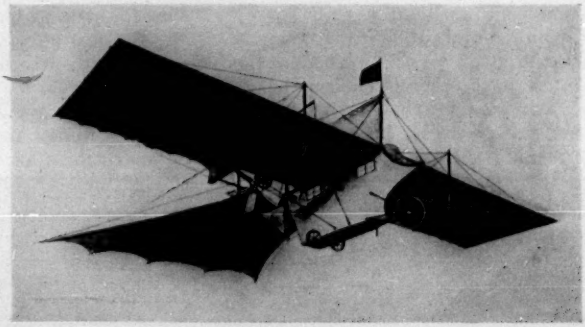


WILLIAM SAMUEL HENSON
(1805–1888).



HENSON'S AËROPLANE.

are double-surfaced; are nicely convex above, slightly concave below; have well trussed hollow spars; threaded strainers to tighten the truss wires inside and out, the outer ones having "oval section" to lessen drag. All beams and ribs are of wood; all surfaces of close fabric, preferably "strong oiled silk." Steam for the engine is supplied by a light boiler of Henson's invention, but now of minor importance in aviation history. His patent claimed any "proper engine."

WIDE PUBLICITY AND INFLUENCE.

Such are the facts gleaned from Henson's patent text and clear drawings in six ample sheets, all dated September 29, 1842. The invention is marvellous for that period. Heralded in many countries it roused praise and derision in prose and verse. It took permanent place in aviation history and stimulated inventors all through the nineteenth century.

Did Henson ever build his mammoth power plane? No, he patented it; he "reduced it to practice." He made no final drawings to guide a workman, but very good patent drawings to clarify his claims. That is all we require, even today, for a valid patent drawing. Did he make successful models? No, he prompted others to do so, notably Stringfellow.* He was merely the original inventor and promotor. He launched the idea and saw it traverse both hemispheres. True, he made instructive experiments with model engines and planes; promoted a stock company, etc., etc.; retired impoverished. But his personal history is of no concern here. His immortal achievement is that he first disclosed so many cardinal elements of airplane design, made people avion conscious and led the way to prodigious success. The airplane of today is a century-long evolution. He started the mighty movement that astounds the world and so vitally affects its normal life.

AILERONS DESIRABLE NOT INDISPENSABLE.

Henson provided for rudder moments in pitch and yaw, but not in roll. He omitted lateral rudders, or ailerons. Many of his followers also omitted them, as too complicating. Yet early pioneers flew well in many parts of Europe, using Henson elements alone. At the Rheims contest, in 1909, Paulhan circled high aloft for $2\frac{3}{4}$ hours in gusty air without torsion-wing mechanism. This useful organ was found unnecessary for exhibition flights. Advantageous it might be, but essential to pioneer flight no, absolutely. Fixed vertical fins, Henson-like, steadied their craft in roll and yaw.

* The little steam model plane constructed by Stringfellow in 1848 was the first in history to fly successfully. It preceded by 48 years Langley's steam model whose stable half-mile hops "first proved conclusively the practicability of mechanical flight." Johnston, Technology Review for June, 1943, gives Henson equal credit for producing the successful 1848 model.

GOUPIL ADDS AILERONS.

Still the worth of ailerons was early recognized. Boulton in 1868 clearly exposed their principle; Goupil, in 1884, explained their use and pictured a refined Henson monoplane with added ailerons, thus providing three-torque control, as in today's most efficient planes for peace or war. So, with Henson's six cardinal elements and Goupil's added one, the aerodynamic invention of the airplane was fairly complete. Practical flying could now be achieved without grave need of further invention.

Had Goupil's successors copied his design they could have spared themselves much ingenious labor, and won success some years or decades earlier. This may be inferred from Glenn Curtiss' quaint experiment. In 1916 he made a "Chinese copy" of Goupil's monoplane,* to demonstrate the prior art, especially the operation of combined rudders and ailerons. The pilot, seated inside the bird-like body, took off in a meadow, returned in circular flight and reported: "there is nothing to it; it controls like any other machine." This flight proved the adequacy of Goupil's system, even though demonstrated by an experienced pilot.

STEAM AIRPLANE FEASIBLE.

Henson deemed his plane mechanically feasible even with motors then proposed. Later achievements confirm his judgment. In 1891 Clement Ader, seated in his tractor steam monoplane, taxied and took off many times in straightaway sustained flight, in hops of 50 to 100 meters over level ground. His engine developed 20 horsepower and with accessories weighed 33 pounds per horsepower. Stringfellow's best engine, with boiler, weighed but 13 pounds per horsepower; Langley's steam engine still less. In 1894 Maxim carried over 10,000 pounds off a level track in a steam multiplane having ample power but defective control. It flew some 300 feet with a crew of 3 men. With all accessories (boilers, pumps, generators, condensers, cooling water) his engines weighed but 8 pounds per horsepower. Had he copied Goupil's version of Henson's transport plane, he might have inaugurated the grand sport of exhibition stunts before the gasoline engine was well developed by the automobile industry.

WORLD'S DEBT TO HENSON

And what do modern airplanes owe to Henson? Their essential primary organs. Discard his patented disclosures, and all the world's mighty air fleets, civil and military, become hopelessly grounded. This cannot be said of any other man. Barring Goupil, can it be said of any dozen men, with all their ingenious homage to their fecund and original precursor?

* Zahm, "Alexander Goupil Inventor of Three-Torque Airplane Control," *Journal Md. Acad. Sciences*, v. II, no. 2, April 1931.

But their homage is most manifest in their use of his patent without paying license fees. They cannot escape it. He covered airframe design so fully that his successors could add only improvements. "Why man he doth bestride the narrow world like a colossus, and we petty men walk under his huge legs and peep about."

This is the first centenary of his invention. If the nations should revive his patent, even for one year, the license fees could erect to him the mightiest monument on earth. They could if they would, in opportune time. And so, let thankful men memorialize immortal Henson, Inventor of the Aeroplane.

December, 1942.

HENSON APPRAISALS.

"The Aeroplane is now known as the invention of Henson."

—H. Chatley, "The Problem of Flight," Ch. 4.

"Henson conceived the idea of a heavier-than-air machine (designed for the transportation of men and goods) on lines which, for the first time, embodied the essential principles of the aeroplane, and by means of which success was ultimately achieved."

—J. E. Hodgson, "The History of Aeronautics in Great Britain," p. 359.

"Le brevet déposé le 29 septembre 1842 par William Samuel Henson est un des plus précieux monuments de l'histoire aéronautique, car c'est la première description complète d'un aéroplane mécanique et l'on peut dire sans erreur que, réalisé actuellement et pourvu de la puissance suffisante, cet appareil volerait certainement. Ce projet est beaucoup mieux conçu, dans son ensemble comme dans ses détails, que nombre des aéroplanes de la glorieuse période de 1907 à 1910."

—Charles Dollfus, etc., "Histoire de l'Aéronautique," p. 75.

"His design contained all the essentials of the modern aeroplane except a positive provision for lateral control in the form of ailerons or other device." . . . they "were to be found incorporated in one way or another in the majority of aircraft during the earliest years of successful flight."

—M. J. B. Davy, "Henson and Stringfellow," pp. 97, 98.

Freezing vs. Dehydrating.—Manufacturers of frozen foods and of dehydrated foods will compete sharply, it is expected, whenever conditions permit free use of all kinds of foods by civilians. Packaging, as well as the preparation of foods, is getting attention in research laboratories and by manufacturers. At present each group is watching developments in packaging and is benefiting from experiments by the other group. U. S. Department of Agriculture scientists are active in both fields and encourage experiments in packaging. Frozen foods and dehydrated foods have one problem in common, the Agricultural Research Administration points out—control of moisture in the finished product. Food dehydrators need to keep moisture out—or their products will spoil. Food freezers need to keep moisture in, for even at zero storage there may be serious loss of moisture, and a loss of as much as 5 per cent. of the moisture in a frozen food lowers its quality. Both groups are working with the latest discoveries in plastic films that are not only waterproof in the ordinary sense, but also proof against the passage of water vapor. William Rabak of the Western Regional Research Laboratory reports that some of the most promising packaging materials are laminated, that is, made up of two or more sheets of moisture-proof material cemented together by a plastic. Such an adhesive, he says, will not only bind the films together but it fills and closes any pinhole imperfections in the films. One of the most effective materials is composed of a thin lead foil attached on one side to laminated kraft paper and on the other to laminated moisture-proof cellophane cemented with a moisture-resistant adhesive.

R. H. O.

Glass Kite String Used for Box Kite for Radio Antenna.—A kite string of glass yarn is used with the box kite that carries aloft the antenna of the portable, hand generator, radio transmitter developed by the Army Air Forces to summon help for fliers forced to make crash landings at sea. The complete transmitter kit for use on aircraft life rafts includes the sending set, an ordinary cloth and wood frame box kite, an antenna consisting of very fine copper wire wound around the glass kite string, two balloons and capsules of compressed hydrogen. The balloons, inflated with the hydrogen, can be used to carry the antenna aloft in the event of a calm. Glass yarn is used as the kite string because of its great strength in proportion to its weight, and because it will not rot or otherwise deteriorate from the effects of salt water, tropic sunlight, rain or dampness. The yarn is twisted and plied from continuous filament glass fibers which can be drawn to indefinite lengths, measurable in miles. The transmitter is so constructed that the operator needs no knowledge of radio or code. When the hand crank is used to generate power, the transmitter automatically grinds out the SOS signal on 500 kilocycles, the international distress frequency.

R. H. O.

OTTO VON GUERICKE: A NEGLECTED GENIUS.

BY

THOMAS COULSON.

PART I.

I.

Occasionally scientists complain that their geniuses are neglected by the lay public. It may be presumptuous, therefore, for a layman to reverse the process and to accuse the scientists of neglecting one of their colleagues. But supporting evidence is not lacking. Every student of physics knows that Otto von Guericke invented the air-pump. What is known or taught of his other achievements? What is known of his life?

Unhappily, Guericke lived in the 17th century and, when he wrote of his work, he chose to do so in a language that is now "dead." These facts in themselves ensure a certain amount of isolation in an age that has little respect for the dead; where the living alone matter and the more one lives the more one matters. This should not excuse the scientist. For the century in which Guericke lived witnessed the invention of six of the most valuable scientific instruments—the microscope, the telescope, the pendulum clock, the barometer, the thermometer, and the air-pump. Guericke was actively associated with the development of the three last, and throws in the independent discovery of the electric machine for good measure.

Yet this important pioneer has, so far, escaped the attention of a detailed study. Only specialists in meteorology, in pneumatics, or in electricity are aware that he did more than discover the air-pump. Anyone who takes the trouble to pursue research into the life and work of Otto von Guericke will not refrain from expressing agreement with an eminent authority who says that "even those who ought to have appreciated his discoveries allowed them to be forgotten." [1] Charles François Du Fay, some of whose electrical experiments were of fundamental importance, was the first of his colleagues to express astonishment that Guericke was allowed to languish in neglect. Speaking of his predecessors in the field of electricity he gives a summary of Guericke's achievements and adds the comment: "One can see from this abridged account of his experiments the foundation and the principle of all those which have been made since with the glass tube and globe, and one cannot refrain from expressing surprise that they have remained so

[1] Wolf, A., "History of Science, Technology, and Philosophy in the 16th and 17th centuries." New York, 1935, p. 305.

long forgotten and that we have not heard about them being repeated and carried further." [2]

Just as the general physics student knows that Archimedes once took a bath and signalized the fact by a scientific discovery of unusual value, so, little is known of Guericke beyond the fact that he once employed a team of sixteen horses to tear asunder the two separate parts of an exhausted sphere. Yet he combined his scientific activity with a public life that justifies comparison with Leonardo da Vinci and Benjamin Franklin.

It is frequently said of Franklin that so much of his life was given to the public service that it was a marvel he could find time for his scientific pursuits. The same remark might be applied to Guericke. His fellow-countrymen allude to him as the "German Leonardo da Vinci" but American students will be more attracted to the analogy with Franklin. However, the analogy should not be pushed too far. Both men were primarily public servants with scientific inclinations. Beyond the possession of an occasional personal characteristic in common, such as an urbane manner or the exercise of a salty humor, there is little other resemblance. If Franklin gave more to life, Guericke gave most to science.

Guericke merits rescue from the obscurity into which he descended upon yet another count. In his time the intellectual life was lived almost wholly within the boundaries of the Church and, naturally, religion and theology were the subject and object of all learning. It was not until the rise of scholastic learning that the Church made any attempt to reconcile religion with science. Eventually Saint Thomas Aquinas and William of Moerbeke succeeded in affecting the reconciliation between Christianity and the science of Aristotle, building a complete world-conception out of Christian doctrine illuminated by Aristotlean thought. As soon as modern science began to sow its wild oats difficulties arose.

In an age when theology was the queen of sciences a state of mind was produced that was little concerned with the drudgery of collecting and sifting facts. Few men took the trouble to verify by experiment the conclusions handed down by Aristotle. It would be wrong to say the ancients rejected all experimentation. One has only to call to mind the bridges and aqueducts of antiquity to realize that experiment and theory must have gone hand in hand. But what experiments they made were simple and served to answer simple questions. Worst of all they were undertaken to test theories rather than to establish facts upon which to found theories.

Scholastic learning followed the practice of the Greeks. It accepted Aristotlean science as final, and concerned itself with precise and subtle

[2] Mémoires d'Académie Royale des Sciences. 1735, p. 35.

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FIG. 1. From the frontispiece of the *Experimenta Nova*, 1672 edition, in The Franklin Institute Library.

logic. If, by any chance, the conclusions of the Schoolmen were found to be at variance with natural evidence and fact, they did not seek to arrive at new conclusions. They shrugged their shoulders and dismissed the matter with the comment: "So much the worse for nature!"

That there was a growing tendency to change this intolerant attitude to nature is shown by Erasmus in his *Praise of Folly* where he says of the scholars: "They hedge themselves about with such an array of magisterial definitions, conclusions, corrolaries, propositions implicate and explicate, and do so abound in subterfuges, that chains forged by Vulcan himself could not hold them so firm that they could not escape by one of those distinctions which enable them to cut all knots as easily as with a two edged ax, so readily do they think up and rattle out new and prodigious terms and expressions."

Guericke was one of the outstanding exceptions to this method (or lack of it). Unlike his contemporary Descartes, but in agreement with Galileo and Boyle, he preferred to put his theories to the test before forming any definite conclusion. "Whatever may be the result of sensory perception, it is preferable to any product of reasoning, much of which may appear to be true in speculation and disputation, but is impractical in reality," he says in his *Experimenta Nova*.[3] When his own experiments showed that accepted theories were not in accordance with observed facts he refused to jettison his observations. Rather he changed his philosophy and adjusted his beliefs to correspond to the facts as he found them.

Men like Galileo, Torricelli, Pascal, Boyle, and Guericke learned the simple truths of recurring facts, and it is because he was successful in selecting facts that had eluded his predecessors and in learning the truth about them, that Otto von Guericke is entitled to rank among the pioneers of modern science. His truths were the constituent parts of a revolution in thought which has not yet reached its climax.

II.

The life of Otto von Guericke [4] is inextricably interwoven with the story of Magdeburg, in Prussian Saxony, "that great and splendid city that stood like a fair princess in the land," as he called it. In his days the city was one of the most important and prosperous in Northern Germany. For over thirty years he towered over his fellow citizens, not because of the fame his scientific achievement brought him, but because the ability he displayed in public affairs marked him out as a natural leader. His family had occupied positions of authority and prominence in the city for three hundred years before Otto was born. Several

[3] "Quod itaque experimentia vel sensu demonstratur, omni ratiocinatione quantumvis probabili ac speciosae, antipondem est; cum multa in speculatione aut disputatione vera videantur, quae tamen nullum effectum in praxi exhibeant."

[4] The only biography is that by F. W. Hoffmann, published in Magdeburg in 1874.

members of the family had been magistrates, a post of greater significance than it is today, and one had risen to the office of Burghermaster. The name had always been written "Gericke" until the eminent scientist, in 1666, was elevated to the nobility by the Emperor.

His father, Hans Gericke, was born in 1555, and entered the service of Stephen Batory, King of Poland, whom he represented as ambassador at the courts of Copenhagen, Stockholm, Moscow (under Ivan the Terrible), and Constantinople. For these services he was raised to the Polish nobility. On the death of his patron he returned to Magdeburg and devoted the years of retirement to the cultivation of his estates. On January 25, 1602, he married his second wife, Anna von Zweidorf. In the following November their son, Otto, was born. He was the sole offspring of the marriage.

Otto must have been a bright youth, for he was entered as a student of jurisprudence in the University of Leipsig at the tender age of fifteen. Even when he went there clouds were darkening the German sky. A vacancy in the throne of Bohemia caused a conflict of claims which was to lead to the war that desolated Germany, and which was to furnish Guericke with another field of opportunity in which to earn distinction. As yet the grim consequences of the Thirty Years War were but obscurely formed in men's minds, but as the opening campaign threatened to engulf Leipsig and to disperse its university students, the retired ambassador judged it prudent to withdraw his young son to the safer refuge of the university of Helmstedt, in Brunswick.

Here he continued his legal studies until the death of his father in 1620. He next appears at the university of Jena, still a law student, but the great change in his life began when he abandoned the foibles of law and departed to Leyden, one of the few universities on the continent which was not under church domination. Here he devoted himself to the study of astronomy, mathematics, and physics.

On the completion of these studies he travelled for the better part of a year in England and France before settling down to the more serious tasks of life.

Lest we should form too high a conception of Guericke's knowledge after all this university education, and thus under-rate his originality of thought, it should not be forgotten that a 17th century education had severe restrictions. After learning his alphabet, the average student acquired Latin grammar and syntax from Donatus and Priscian. A knowledge of logic, rhetoric, poetry, and arithmetic would then be derived from the works of Aristotle, Cicero, and Boethius. More advanced students would take a course of geometry, astronomy, and physics. Although the invention of printing and the renaissance of learning released upon the world a new and spontaneous feeling for learning, the spirit spread abroad was that of humanism. The result of the process was to change the entire culture of Europe, but the

changes brought about in science were far less conspicuous than in other fields.

The foundation of Guericke's training must have been laid upon the works of Aristotle and his Arab commentators. He probably knew about the interesting work on mechanical contrivances carried out by Ctesibius and Hero of Alexandria, and the earlier work of Galileo in dynamics. Exactly how far he went in mathematics it is impossible to say. It is easier to say how far he might have gone. Snell, the Professor of Mathematics at Leyden, was a brilliant teacher, best known for his work in the laws of refraction, and it is highly probable that he progressed with his time. Euclid's *Elements* had been translated by Adelhard of Bath, and this was the standard text-book in European universities. Beyond this Guericke might have learned simple and quadratic equations, the fundamentals of trigonometry, and probably something of statics and hydrostatics. This much he *may* have known because such knowledge was available.

Of one thing we may be certain. The finished work gives no suggestion that Guericke laid supreme stress upon number and quantity. He was too early for mathematical demonstration.

In astronomy the work of Galileo, Brahe, and Kepler had established the value of the Copernican theory of a heliocentric universe and had made the science a much more popular subject of talk and study than it is in our days. Guericke would learn all this (but not from Galileo's famous *Dialogues*, which was not yet published) while he was at Leyden.

Taken all in all, we may regard Guericke as an unusually well educated young man when he had completed his studies. His transfer from one university to another and his travel in England and France must have given him a more extensive knowledge of men than most youths of his time were able to obtain. Left in comfortable circumstances by his father, he had to decide for himself how his future must be charted. In those days, as in all times of human history, there was work to be done by those who wished to do it. It is easy enough to find work but not so easy to find employment for one's leisure. The solution which Guericke provided to his personal problem ensured the full exercise for his talents and made him a man of distinction in more fields than one.

As befitted a man of his training and family tradition he sought to make himself useful in the affairs of his community. Magdeburg was ruled by a council, the members of which appointed the magistrates. Not only did these officials administer justice (and administer it so well that Magdeburg law and justice was held in high esteem throughout all Germany), but they regulated the revenues and public affairs very much as if the town were an independent state. Guericke was elected to the city council, and at the age of twenty-four (1626) was elevated to the bench of magistrates. In addition to his task of administering justice, for which his legal training qualified him, his other talents were

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given exercise in his selection to supervise the city's fortifications. This latter post chanced to assume a position of unusual importance at this stage of the city's history. Not only was Magdeburg regarded as a city of considerable strategic importance and fortified accordingly, but it was inevitable that it must play an effective part in the war which was spreading over Germany.

However, between his manifold civic duties he contrived to find time to take a wife, thus uniting himself to the noble von Alemann family. There were several children of this union but only a son, also called Otto, was to survive.

It is a matter of regret that only the scantiest traces of Guericke's private life have been preserved. But he seems to have been of a happy, jolly, and friendly disposition. Public service engrossed him to such an extent that his existence is best followed through official records and little is known of his friendships. By the year 1629 he was so deeply immersed in the affairs of the city that for the next forty years he was never free from public office. In all measures of the community, whether for peace or for war, he was in the forefront of the city's struggles, and they were many and bitter.

Trouble began in March, 1629, when General Wallenstein, incensed at the refusal of Magdeburg to receive and maintain an Imperial regiment, and to pay an accommodation of 300,000 dollars, laid siege to the city. Guericke has left a moving picture of the tragic days that followed in a book entitled *Die Geschichte der Belagerung und Eroberung von Magdeburg*. For seven months the burghers offered a desperate resistance. No breach could be made in its fortifications, nor could any assault storm its steadfast walls. Finally, Wallenstein gave up the siege, saving his face by obtaining a fraction of the sum he had demanded.

However, the respite for Magdeburg was short. The new city council had barely been elected to office when the siege was renewed by General Pappenheim. In March of 1631 the Imperial troops intensified their efforts to reduce the city. A strong army, supported by 86 heavy guns began battering at the walls of the fortifications of the city and its islands. The fortitude of the defenders could not hold back the superior numbers nor could the skill of their learned military engineer repair the damage created by the heavy equipment with which Tilly, in person, reinforced his lieutenant. After two months a breach was affected in the walls and the city was carried by assault. The scene that ensued is one of the memorable features of this terrible war.

That night of May 10 with all its horror must have seared its way into Guericke's memory, for its far-reaching effect was to be his concern for many a year to come. The slaughter must have been terrifying, for later accounts placed the deaths at 20,000. Only the cathedral and the

Liebfrauenkirche and about 140 houses, most of them poor fishermen's huts on the river bank, escaped the flames.

It says much for Guericke's honor that he was among those few devoted citizens who fought up to the last minute in the city streets. He stood by the soldiers until all hope was gone, delaying his own escape until the last minute, when it was no longer possible to rescue his

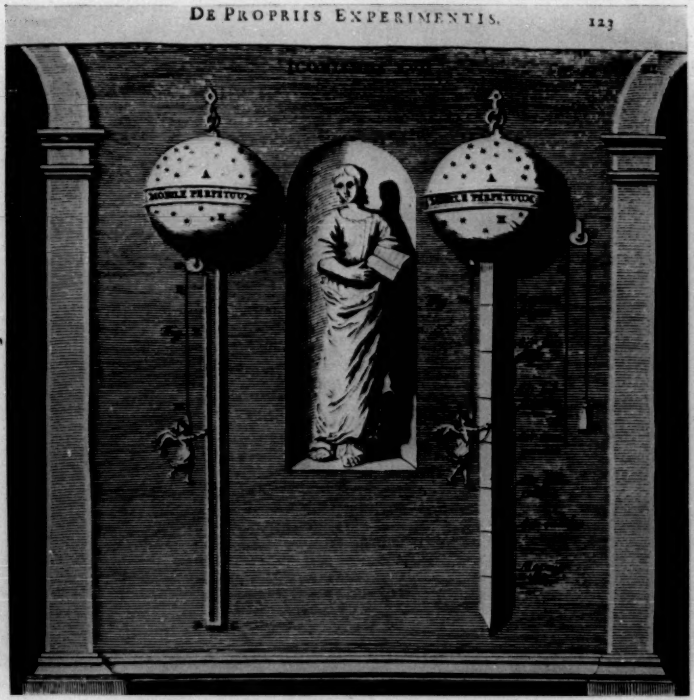

FIG. 2. Guericke's early thermometer (From the *Experimenta Nova*).

property. When he reached a place of safety he had no more than what he stood up in. Guericke was able to find a refuge in the home of an uncle who did not share his political sympathies.

After the departure of Tilly's troops, the sad task of reconstruction was bravely undertaken. Much of the work of restoration descended upon Guericke. Since the community's funds had been exhausted he spent liberally from his own resources—a fact that was soon to receive

a grateful recognition from his generation. It speaks highly for the city council and for the burghers who had escaped and who now returned to the burned-out shell of their city that the commerce of this once prosperous community was promptly resumed, the ravages of war hastily repaired, and Magdeburg's position of prominence restored. Contemporary writers all speak with admiration of such an early recovery.

Before he engaged in rebuilding the city Guericke was back at war. After the fall of Magdeburg he joined the army of Gustavus Adolphus of Sweden in his victorious sweep through Germany. He played a conspicuous part in the siege of Erfurt. It is significant of the ignorance that prevails on Guericke's life that this episode in his career serves to justify some writers of scientific text-books to describe him as having been appointed to the post of engineer to the city of Erfurt. In point of fact, he was Quarter Master General and Chief Siege Engineer with the Swedish forces when they laid siege to that city.

After the brilliant victory of Lutzen (which cost the victorious Gustavus his life) Guericke found service with the Saxon army. For a while it looked as though the Protestant cause was about to triumph, whereupon the city engineer returned to Magdeburg to play his part in the arts of peace. Guericke threw himself with zeal into the work of rebuilding the city, freely employing funds from his private purse. Since he toiled unremittingly at the public task without recompense his private affairs grew in disorder while those of the city revived. As a reward for his devotion and to relieve him from financial embarrassment, the administration released him from the obligation to pay taxes.

Guericke now enters upon a new phase of his public career. He becomes a diplomat. Before entering into these it is as well to point out that the period immediately preceding his ambassadorial duties was the time of his earliest scientific researches (1632–38). It was not until he had entered his fortieth year that he begins his diplomatic work.

In 1642 we learn of him in Dresden and Leipsig where he was detained for three years upon the preliminary stages of the treaty that brought peace to Germany. At the conclusion of this work he returned to his home in time for tragedy to strike at him in the death of his wife. In 1645 the city paid him the greatest honor within its gift in electing him Burghermaster, appointing him one of the four officials who held this title. He was likewise appointed counsellor to the Elector of Brandenburg. During the years 1646–7 he represented the city in the peace negotiations at Osnabruck which resulted eventually in the Treaty of Westphalia. Home for a couple of years he returned to Osnabruck, thence to Nüremberg, and before the end of that year he was on his way to the imperial city of Vienna. Here he remained for two years, being received by the Emperor Ferdinand III. In 1652 he was in Prague, to which city the imperial headquarters had been transferred.

In the same year Guericke remarried but, as his wife died shortly afterwards he and his son by the earlier marriage (who was also a widower) went to live with Guericke's mother on their manorial estate. The ensuing few years were probably the nearest Guericke had ever approached to leisure since he had assumed public office. This was the time of his later experiments.

He was to make one more journey from home, and the date and occasion have a special importance to us, as it definitely fixes the time of his principal scientific demonstration. In 1654 he attended the meeting of the Imperial Diet at Regensburg, in Bavaria. It was here that, before the Emperor and a host of lesser princes, he performed the feat by which he is known to every schoolboy. But for the highly spectacular manner which he employed to demonstrate the principle of atmospheric pressure, it is probable that the credit for having discovered it, and for having invented the first air-pump, might have passed elsewhere.

The demonstration was witnessed by spectators who did not hesitate to proclaim that Guericke's experiment had furnished them with a highly diverting spectacle. It cannot be said, however, to have convinced many of the eye-witnesses that a vacuum had been achieved, for the belief, based upon Aristotle's assertion, that nature abhors a vacuum, was much too strongly held to be shattered by a single illustration. One of these spectators was the unconscious means of providing the second piece of evidence to establish Guericke's priority to the invention.

Three years after Guericke performed his last political mission and his great demonstration occurred the second event which establishes his precedence of Robert Boyle. This was the publication of a book by Kaspar Schott.

Guericke was neither affiliated with any university nor was he a member of a learned society. Like so many other pioneers of modern science he was an enthusiastic amateur. His work was made known to a limited circle of co-workers through the medium of personal communications. Some chosen individual acted as the focal point for this interchange of ideas. Such a man was Kaspar Schott, a Jesuit priest who held the post of Professor of Physics and Mathematics at Warzburg University. Although by no means in sympathy with Guericke's idèa of destroying some theories concerning the laws of the universe advanced and defended by the Church, Schott was not adverse to testing Guericke's claims and truthfully informing his correspondents of the results he obtained.

After the successful demonstration at Regensburg, Guericke entrusted his apparatus to Johann Philipp von Schönborn, Elector of Mainz and Archbishop of Warzburg, who had it conveyed to the latter city. Here Father Schott repeated the experiments and, with the

inventor's approval, published an account of what had been accomplished.

Schott published his *Mechanica Hydraulico-Pneumatica* in 1657.[5] This was the work which fell into Robert Boyle's hands and inspired him to repeat Guericke's experiments, work he had long intended to perform but had always deferred, he said. Reading the book prompted him to instruct Robert Hooke, the greatest instrument maker who ever lived, to construct an air-pump that remedied some of the defects in Guericke's.

We have paused here to emphasize the importance of these proofs of Guericke's priority only because of the two dates, that of the Regensburg demonstration and that of Schott's publication, which are vital in proving that Guericke's work preceded that of Boyle. Since Guericke's own account of his work did not appear in print until 1672, whereas Boyle announced his in the *New Experiments Physico-Mechanicall touching the Spring of the Air*, published at Oxford in 1660, it might be imagined that the Englishman was first in the field.

Although Boyle confessed that he rarely obtained an extreme degree of rarefaction with his pump, while Guericke achieved a much greater success in this respect, he eclipsed the real inventor so completely that, in their literary ardor, many contemporary writers spoke of *any* degree of rarefaction as a "Vacuum Boyleanum" and of an air-pump as a "Machina Boyleana."

After the two events mentioned had thrust him upon the notice of other philosophers and scientists, Guericke began to suffer from the consequences of his originality. Orthodox churchmen sprang to the defense of their cherished doctrine, based upon the encyclopaedic knowledge of Aristotle. To these men who believed in a universe constructed of the fabric of thought, the air presented a continual perplexity. They found it all pervading. No nook or cranny could be protected against its insidious penetration. Make or find a space and air instantly rushed in, if it were not already there. To these men such a thing as a void was unknown because Aristotle had said that it could not exist. Of what use was it, then, to make an attempt to prove that it might be created?

Confronted with Guericke's claim to create a vacuum at will with the aid of his air-pump, the Schoolmen attacked him with might and with main for his insolent heterodoxy. One of them, Dr. August Hauptmann, stated in his *Berg Bedencken* (Leipsig, 1658) that Guericke's claims were false since "it would not be possible to either angel or devil to bring about a vacuum." That succinctly expressed the Schoolman's views toward Guericke and his claims, so that he was constrained to undertake his own defense. In the year 1660 he began to write an account of his conception of the universe and to give a detailed descrip-

[5] To be followed in 1664 by his *Technica Curiosa sive Mirabilia Artis*. This book contained additional information, chiefly upon experiments which Guericke had conducted in the interval.

tion of the experiments which had enabled him to demonstrate the falsity of some commonly accepted beliefs.

With the carelessness that is almost customary when writing of Guericke, several writers have said that he withdrew from public life in order to write this book. The facts show that he was still Burghermaster of the city of Magdeburg and was to remain so for another sixteen years. Between his official occupations Guericke somehow contrived to find time to make more experiments and to work at the book. The writing was finished on March 14, 1663 but the foreword is not dated until the same day seven years later. Illness and pressure of public work delayed publication until 1672.

The nature of the city business that interfered with the preparation of the book for the press arose from the termination of the Thirty Years War. After the Treaty of Westphalia had been signed some territorial adjustments brought to an end the vexed question of the archbishop's temporal power over Magdeburg. The see was converted into a secular duchy in favor of the Elector of Brandenburg. Guericke swore allegiance to his new overlord and was appointed to the office of Burghermaster for another period of ten years. At the same time he was elevated to the nobility, and from this date we find him using the new spelling of his name.

This change in the status of the city was probably a relief to Guericke in more ways than one. He obtained the protection of a strong ruler against the possible disapproval of either church. The martyrdom of Michael Servetus and Giordano Bruno were recent enough to caution him that the authority of the Church was not to be despised. Guericke was already thirty years of age when Galileo was forced by the Inquisition to recant his astronomical work and to abjure the Copernican theory. Opposition did not come solely from the Vatican. Luther and the reformers were firmly opposed to the Copernican system, nor should it be forgotten that the Protestant Theological Faculty of Tübingen had condemned Kepler in 1596 for asserting exactly the same doctrines as those for which Galileo was condemned in 1632. After this incident Kepler sought and found protection under the Jesuits.

With such general disapproval for scientific advancement of thought it must be acknowledged that a man had to proceed warily. Not so Guericke. Whatever reputation he enjoyed for loyalty, honesty, and justice with the more substantial burghers, it cannot be denied that the devout must have crossed themselves whenever, in pursuit of their lawful occasions, they had to pass the Burghermaster's house.

There, before their very eyes, was a diabolical contrivance which predicted the approach of storms. While they reluctantly admitted that the forecasts were not to be scoffed at, they had the strong suspicion that this mayor of theirs might be an exceedingly unpleasant neighbor. Once a just Heaven had launched its displeasure upon him in the form of

a thunderbolt that fell upon his house and wrecked a number of his infernal toys. One never knew what further punishment might be reserved for an unrighteous creature who tampered with the spirits of the air, whom he enclosed in glass bottles, tubes, and globes, that he might torture them and enjoy their sufferings.

This brazen defiance of the prevailing superstition throws a curious side-light upon Guericke's character, for he cannot have remained long in ignorance of the horror aroused in the minds of the simple and the uninformed when he converted scientific instruments into prankish toys to the derision of their beliefs.

The fact was, that sometime before the year 1660, Guericke had made himself a giant barometer which towered above the fourth floor of his house. Instead of using a needle to indicate the degree of atmospheric pressure, the inventor had placed a mannikin on the top of the column of liquid. With a mischievous sense of humor Guericke concealed the tube from the view of the spectators behind a wooden framework. All that the uninitiated could see was the mannikin. And that not always. When the weather was agreeable the mannikin, naturally, was hoisted into sight by the column of liquid, but no sooner did the atmospheric pressure diminish, heralding the approach of bad weather, than the infernal mannikin sank from sight—into the Burghermaster's home to shelter from the rain, declared the pious burghers!

Nor was that the full extent of his sins of commission. Before long the wretched little weather prophet was joined by a winged angel, which was Guericke's impression of a thermometer.

Again favoring the gigantic, he built his thermometer twenty feet high, and again he concealed the working parts behind a framework, painted bright blue and sprinkled with golden stars. Against this background dangled the angel pointing infallibly to the current temperature. No evening chill succeeding a day of blistering heat caught the angel unawares. She did her duty faithfully as a good angel should do. But she failed to dispel the honest doubts aroused in the minds of a peasantry wholly ignorant of the ways of thermometers.

Then, to crown all, came news of a book that told of the necromancy that went on within the house. A French lieutenant of police from Lyons, Balthazar de Monconys, had set out in 1663 to discover vestiges of the philosophy of Tresmegistus and Zoroaster. He got wind of some strange goings-on in Magdeburg and, like a true policeman, made a detour to investigate. Monconys was delighted with the visit he paid to Guericke but his account of it did not help matters. In his *Voyages* (Lyons, 1665) Monconys told of the singular virtue of a globe "made of nine minerals" with which Guericke pursued a feather around the room, preventing the feather from falling to the ground without touching it. Of course, the globe was no affair of nine rare minerals, it consisted of one, and that common sulphur. But when news of it, with the in-

evitable embroidery of verbal repetition, reached Magdeburg one may conjecture what was the local opinion of what scientists now recognize as the first electrical machine.

It can have required no small amount of moral courage in those days to trifle openly with popular doctrines. Guericke's conviction that Reason was advancing her frontiers in men's minds must have been very strong indeed to give him the courage to defy the scholars and to ignore the beliefs of the masses.

How great a part his radical views may have played in the turn of public opinion against him can only be a matter of conjecture. The fact remains, that when his turn of office expired in 1676 there was a revulsion of feeling against him. He still retained public office, but he was relegated to the subordinate office of Supervisor over the apothecaries, a position he occupied until 1678. But most significant of the change against him was the evidence conveyed in the action of the new generation of public men. They showed that when a man's term of usefulness has expired his contributions to human advancement may be overlooked and his sacrifices to the commonweal may be disregarded. Narrow provincialism could neither grasp the measure of Guericke's scientific achievement nor treat an old and faithful servant with generosity.

No sooner had he vacated the mayoralty than the city's Board of Assessors opened an irritating campaign against the old man. Not content with rescinding the ordinance exempting him from the payment of taxation, which had been passed to reward him for his sacrifices during the city's reconstruction, the Board further assessed his property upon a scale that rather suggests their resolution to compel him to pay all the deferred taxes. Thus, Guericke's old age was embittered by the pin-pricks of a generation that had either never known or, in their new found prosperity, had forgotten the spirit that had been born on that night of horror when Tilly's troops swept through the city streets.

He was still engaged in a minor campaign with the ungrateful officials when the terrible epidemic of influenza which spread over Germany in 1681 began to advance upon Magdeburg. It was difficult to find an asylum in the neighborhood, for the whole moist plain was fretted with fever and haunted by plague. The indomitable spirit that had faced moral and physical danger with courage was too feeble now to confront a new one. At the time when flight became necessary, his one surviving relative, his son Otto, was residing in Hamburg. To this city went the feeble old man to find a refuge under his son's roof.

It was there that death overtook him on May 11, 1686, in his 84th year.

III.

Otto von Guericke would be entitled to a position in the history of science had he done no more than invent the air-pump. However, we shall see that he did a great deal more than that when we examine his own account of the work he performed. This was given to the world in the year 1672 under the title *Experimenta Nova, ut vocantur, Magdeburgica de Vacuo Spatio*,[6] and published by Johann Jansson of Amsterdam.

Primarily concerned with defending himself against those who derided his conclusions as much as they attacked the validity of his experiments, Guericke expounds at length his conception of the entire universe. Most of the book is devoted to cosmology. Its defects and its qualities are those of all the great amateurs who are also pioneers. Lack of a technical vocabulary often makes his meaning obscure.

The first book deals with the universe in general; the second with interstellar space; the third, and most important, with his experiments; the fourth with "mundane virtues and other things thereon depending"; and the remainder to comets and other astronomical matters.

The arrangement of the books in this order calls for some explanation. Had Guericke been writing in our own day he would, undoubtedly, have given his experiments pride of place, and, after describing what he had done, would have erected his theory upon this basis of fact. Instead, he offers his theory first and, later, presents the experimental proof very much in the manner of a man who has questioned nature and obtained a reluctant admission that his theory was in accordance with the natural evidence. This method is not peculiar when we recall that Guericke was writing in the 17th century. He merely followed the practice of an age that based its beliefs upon speculation.

According to the Schoolmen, the first step in knowledge was to secure a correct set of concepts to embrace all things, and then to deduce all things from them. It is an admirable plan if only one can obtain the concepts. The trouble lies in the fact that they do not exist ready-made. They have to be grown from seed, as it were. When physicists tried to make such a plan work they became entangled in a mesh of contradictions, so that progress could be made only by ignoring or distorting the testimony of their own observation.

Happily, Guericke was a practical engineer. When he found that

[6] The full title reads: Ottonis de Guericke/Experimenta/Nova (ut vocantur) Magdeburgica/de/Vacuo Spatio/Primum a R. R. Gaspare Schotto e Societate/Jesu et Herbipolitanae Academiae Matheseos/Professore;/nunc vero ab ipso Auctore/perfectius edita, variisque aliis Experimentis/aucta./Quibus accesserunt aimul certa quaedam/de Aeris Pondere circa Terram, de Virtutibus mundanis, et Syste/mate mundi planetario, sicut et de Stellis fixis, ac Spatio illo immenso quad tam/intra quam extra eas funditur./Amestelodami./Apud Joannen Jansonius a Waesberge, Anno 1672./Cum Privilegio S. Caes. Majestatis.

conclusions based upon speculation could not be applied with happy result to such matter-of-fact problems as the irrigation of fields or the construction of fortifications, he did not dismiss the problem as insoluble but, suspecting that even Aristotle might err, he sought to provide practical solutions.

It was this insistence upon experimentation which makes Guericke one of the outstanding figures of the 17th century science. He realized as few of his contemporaries did, that as knowledge increases, concepts change; that the conception of a thing is not its definition in a few well chosen phrases; but that it must embrace a whole history of the thing itself. His practice of engineering had taught him that a study of words was no substitute for a study of things, and that a man did not become an engineer by learning the names of his tools. "Skill in disputation is unavailing in the realm of science," he wrote in defense of his method, to the amazement of his contemporaries who regarded ability in dispute as the ability to discern the truth. His scientific method might not differ from current practice but his literary presentation was in the manner of his own times.

Desiring to erect a true conception of the universe he set about building it brick by brick. In reading his book one is forced to realize the extreme narrowness of the views current in his day. It is all to his credit that he was able to shed the conventional views, and by sheer force of an independent intellect, to create a new conception of the earth and its position in the universe in the light of his own experience.

Again, it is necessary to emphasize that the influence of Aristotle upon the minds of men was incalculable. He was "The Philosopher," and for almost two thousand years his works remained the standard authorities on science. So little had science progressed during those two thousand years, that Aristotle's assertion of a fact was considered at the beginning of the 17th century as the best proof of its truth. Many of his ideas were mere opinions but they were accepted as articles of faith, thus presenting serious obstructions to the advance of science. Thus, he believed that motion could only be maintained by the continual application of force; that a vacuum could not exist; that certain things were light by nature and tended to rise spontaneously, while others were heavy and must accordingly sink.

Such conceptions as these could only be shown to be false after much bitter controversy and behind every attempt to demonstrate their error loomed the dread shadow of persecution for heresy. In assessing the value of Guericke's book we must never forget that the ways of science in his days were as full of wild wonder as any have been. The reports of the lonely and audacious pioneers were grave and terrible things that shook an authentic heaven and shattered an incredible hell. In our day we have lost that sense of wonder. What we must remember is, that things were different in Guericke's day. There was a dreadful

excitement in the tale of a planet, and contact with material things was regarded as unworthy of a philosopher.

Guericke begins his study of the universe with the miracle of Joshua. He seeks to harmonize this with the views of Copernicus—not a propitious start for a scientist. But he boldly grapples with the Schoolmen who based their objections to the Copernican system upon the Bible, and he seeks to furnish conclusive evidence of their error. He enters with gusto upon such metaphysical controversies as the geographical location of heaven and hell.

Guericke's views upon interstellar space were of greater importance in his days than in ours, but we must not lose sight of the fact that he was led to experimentation through the contemplation of astronomical subjects. For all his passionate care for details, it was the dim shape of the larger vision that held him. Yet he would make no audacious flight into space until he was securely tethered to actuality. If he provided the earliest solutions to problems in pneumatics it was only because he tried by experiment to create the medium in which he thought the stars must move.

It should be observed that it was not Guericke's purpose to obtain a vessel devoid of air. His purpose was *to exhaust the air which was in the vessel*. The principle he was seeking to prove was, that air possessed the power of expanding itself into a greater space when the force, which he suspected was compressing it, was removed. He says expressly that his contrivance of the air-pump occurred to him accidentally when he was occupied with experiments in which he found that the air would really expand and fill a much larger space than what it usually occupied, and that he had found no limit to its expansion.

This was a doctrine quite new, and it required a philosophical mind to view it in a general and systematic manner. It must be owned that Guericke's manner of treating it is equally remarkable for its ingenuity and its modesty.

To Guericke the air was not one of the four elements as Aristotle said it was. Compelled to advance some explanation for his rejection of this commonly held belief, he was satisfied to conclude that it is an exhalation of natural bodies. Beyond that, all he had to go upon was the knowledge that heat and cold will change the volume of air, and he must have known from the work of Hero that air may be compressed.

Otherwise, Guericke finds himself unable to obtain an accurate picture of the Copernican conception of the universe and the astral space it involves, through personal observation. So he tried to arrive at an approach to the tremendous dimensions it embraces by means of a mathematical explanation (Book I, p. 26). He applies himself to a study of the smallest particles, which not even the microscope can detect, those particles we call atoms, and which should be individual

but inseparable. Thus the particles of air, fire, water, etc. are so small that they cannot be imagined, yet they cannot penetrate glass or metals (Book II, p. 70).

But air was thought to be an effluvium of water and the earth, covering the earth and extending to a certain distance beyond—almost half-way to the moon (Book III, p. 85). Above and beyond this lies the full expanse of space, an enormous void which contains the universe. One must make the distinction between a vacuum and this empty space, this immeasurable void. Just as death is the extinction of life, and darkness is the absence of light, so is a vacuum the deprivation of matter from space—in fact a nothingness that one may imagine but not grasp. All bodies and all natural substance have been removed from this space.

So many theories had been advanced respecting this void, and they were so divergent, that Guericke was inspired with a longing to explore it (Book I, p. 54). This longing was the starting point of the so-called Magdeburg experiments. "Any space on the surface of the earth if emptied of particles will not remain empty, but is filled with air, in much the same wise as a fish in the water; when it changes position, water flows into the space it occupied" (Book III, p. 73).

With this brief outline of Guericke's philosophy let us examine in greater detail Book III, *De Propriis Experimentes*, which Wolf [7] describes as "one of the most weighty and instructive monographs on physical topics" of the period. This section of the book describes the apparatus which Guericke constructed for the performance of his various experiments and the results he obtained with it. That portion of the *Experimenta Nova* which relates to the mundane virtues we shall leave until the last, because therein lies the account of the first electric machine and the conception of the earth which Guericke formed from its use.

IV.

While engaged upon the contemplation of interstellar space, Guericke conceived the bold idea that many problems might be simplified if nature, instead of abhorring a vacuum, could be induced to tolerate one. He determined to make the effort to test nature.

"I thought of filling a beer or wine cask with water," he explains, "and caulking it everywhere, so that the outside air could not enter. A metal tube was introduced into the lower part of the cask by means of which the water could be drawn out. Then the water remaining in the cask, in consequence of its own weight, would sink and leave behind in the cask a space devoid of air and, therefore, of any natural body."

There arose the difficulty of a suitable pump, one which would be

[7] Op. cit.

capable of preventing any air escaping into the cask. An ordinary brass pump, such as was used by the local fire brigade, formed the basis from which he started. First, to the piston he attached a plug which was made as near as could be so tightly fitting that no air could escape past its sides. Next two leather valves were introduced into the pump, one of them was to admit water into the cylinder, and the other was to permit its ejection. The pump, with these additions, was fastened securely to the cask by means of a four-lugged ring. The first trouble arose over this ring, for the force to be applied in moving the piston had been entirely under-estimated.

From the beginning of operations the workers experienced difficulty. After the first stroke or two with the piston so much energy had to be applied that the screws of the ring snapped off. Hèavier screws were inserted and the work resumed. The resistance of the piston increased to such an extent that three stalwart men had to be enlisted in the work. Even then it was so laborious that they were compelled to pause to catch their breaths. It was in one of these pauses that Guericke's ear detected "a rustling sound, as if the water were boiling vigorously." Somehow or other, he concluded, air was finding its way into the space within the cask caused by the withdrawal of the water.

Without realizing the cause of this unexpected obstacle to the fulfillment of his hopes, Guericke hastily concluded that he must take steps to exclude any possibility of the outer air entering the cask. Ordinary caulking with pitch was insufficient.

"I prepared, therefore, a smaller cask which I placed inside the larger one. After a longer pipe had been attached to the pump and carried up through the bottoms of both casks, I filled the smaller cask with water, sealed up its opening, and, after also filling up the larger cask with water, began the task all over again."

This time he did not doubt that the desired vacuum would be achieved. But he had not counted on nature's reluctance to tolerate the vacuum. He was again confronted with failure.

The actual task of pumping was still harder with the lengthened pipe, since several hours were required for the evacuation of a moderately sized vessel at the best of times. Again and again the men working the pump were compelled to rest and, for the second time, Guericke heard an ominous sound issuing from the cask during one of these rest periods. This time he describes it as "a varying tone, interrupted from time to time like that of a twittering song-bird." This noise continued for three days, at the end of which time the smaller cask was opened for inspection. To his great astonishment Guericke found it was filled for the greater part with water, although work had been abandoned when the pump had failed to draw any more water from it.

Worst of all, there was some air in the cask.

Although the evidence seemed to point unerringly to the conclusion

that nature was obstinately abhorring the vacuum, Guericke sat down to figure out by what possible manner water and air could have penetrated the smaller cask after the pump had indicated that none was present.

After some painstaking investigations he arrived at the conclusion that the wood of the cask was porous and could not exclude air if it were under high pressure. There had been sufficient indications of approaching success to encourage the philosopher to persevere with some less porous material than wood. He decided upon copper.

For the third attempt he had constructed a copper globe (which Schott insisted upon calling "cacabus") and this he decided to exhaust directly. This globe with a capacity of from 60 to 70 Magdeburg quarts, was furnished with a brass stop-cock, at the top. The pump was introduced through the bottom, secured, and made airtight. Two men began to pump. So excessively hard was it to move the piston that the services of two others had to be employed, and even then work was difficult. The four toilers had barely succeeded in achieving a partial vacuum when the globe suddenly collapsed with a loud report. "The metal was crushed in as cloth can be rolled between the fingers," commented Guericke in his amazement.

In spite of these disappointments the inventor refused to be discouraged. He wanted to know why the copper globe had collapsed. Here we observe the true discoverer's mind at work. For it is only when a man is looking for something that he finds anything. He may not find what he is looking for, as Columbus learned when he sought India and found America, but the conscious search for something makes the intellect alert and leads to the observation of many things that would pass unnoticed.

Before arranging for any further steps in the creation of a vacuum he must learn the cause of his latest failure. "I believe that the cause of this was the inexpertness of the workmen who, perhaps, had not made the globe exactly spherical," he reports. "The flat part, where ever it was, could not support the pressure of the surrounding air, whereas on the other hand, an exactly made sphere could easily have sustained it on account of the mutual support of its parts, which sustain each other in overcoming resistance."

With this quite satisfactory conclusion to encourage him Guericke had made another globe in which greater attention was paid to the perfection of its shape. A fresh effort was made to exhaust this and, after much strenuous labor, it was observed that no more air passed from the upper valve of the pump. Guericke might well have given expression to Archimedes' triumphant exclamation "Eureka!" For he had found what he sought—a vacuum.

But now that he had found it what was he going to do with his precious vacuum?

He had so little anticipated having any practical use for it that he was unprepared for any other than the most naive observations.

"On opening the stop-cock the air rushed with such force into the copper sphere that it seemed as if it would draw in a man standing before it. If the face were brought fairly near, the breath was taken away; and one could not hold one's hand above the stop-cock without the risk that it would be drawn violently to it."

Notwithstanding the labor involved in exhausting the globe Guericke repeated the process so that he might make some simple experiments. He thus observed that, when left for a day or two, the globe filled up again with air. Investigation revealed that this was due to the seepage of air past the plug of the piston, through the valves, and through the stop-cock. If these defects were to be remedied some radical improvement must be made in the pump, thought Guericke. Moreover, he was obtaining a clearer vision of what he might try to do with a vacuum. Once involved in the quest for knowledge, the analyzing and curious mind of Guericke began to sift, and probe, and acquire for the sheer love of it. His simple mind, sick of subtleties, sought the refreshing truth.

What he wanted most of all was a glass globe so that he might see what was going on inside when it was exhausted of air. Accordingly, he designed a new pump, the third, which would embrace all the improvements he had decided were necessary.

This new pump is the design with which we are most familiar, but before proceeding to describe it let us see what has happened to the first. Naturally, the first of all air-pumps should be a valued treasure in some science museum. Its history has been traced as far as possible by a painstaking German scholar [8] who learned that the pump had passed into the possession of one of Guericke's friends of student days, a man called Werner, who had passed it on to his son. At some time Dr. Christian Herarus, a chemist of Stockholm, had taken it to Sweden. As late as 1734 it was in the possession of Dr. Daniel Mentös, Professor of Mathematics at Lund. After that all trace of it has been lost but there is still a chance that it may be recovered among the clutter of some Swedish attic.

The pump which is displayed in the Deutches Museum, Munich (there is a replica in The Franklin Institute Museum), is that which Guericke constructed after Kaspar Schott had informed him in a letter dated February 17th, 1662, that Robert Boyle had improved upon his air-pump. From the account given by Schott the inventor recognized the superior efficiency of Boyle's pump. He promptly made a better one.

[8] Berthold, G., "Die Originalluftpumpe Otto von Guericke's." *Annalen der Physik*, vol. 54, 1895, pp. 724–6.

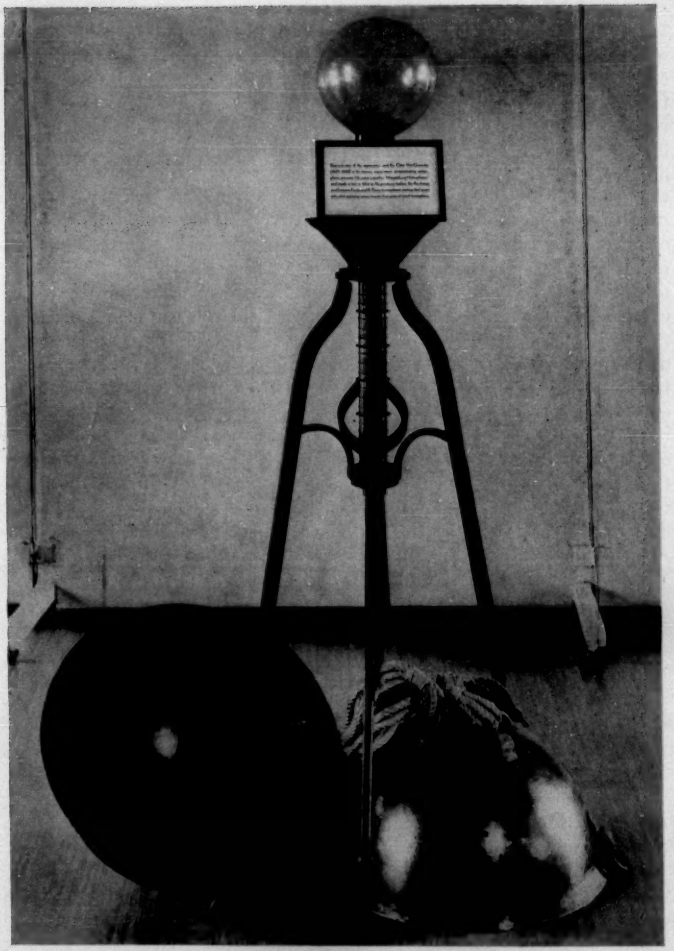

FIG. 3. Replica of the Guericke air pump and the Magdeburg hemispheres in The Franklin Institute Museum.

This time the pump was mounted on a tripod screwed to the floor. The cylinder of the pump was considerably shortened and the piston was operated by a lever, so that one man could do the exhausting without undue exhaustion to himself. As will be seen the cylinder ends in a tube, into which the conical end of a glass receiver is thrust, and sealed by a detachable ring. Over the mouth of the receiver was fitted a leather valve. This valve opened at the downward stroke of the piston and allowed air to pass from the glass receiver out into the pump. At the upward stroke, the valve closed, and the air was expelled from the pump through an external valve.

As a precaution against air entering the receiver its joint with the pump cylinder was set in a funnel-shaped receptacle which was then filled with water. With the same object in view, the lower end of the cylinder was also immersed in a water-filled container.

Not only do we see in Guericke's original pump all the essential details of the modern air-pump, but his method of excluding air from the joints of his apparatus by immersing these joints in a liquid, is the only efficient method which has, to this day, been found effectual. Experiments must frequently be conducted where exclusion of the air is necessary over long periods. In such cases it has been found necessary to construct little cups at every joint, and to fill them with oil or water.

In a letter to Schott [9] written in 1662, Guericke describes some very ingenious contrivances he introduced for producing complete rarefaction after the elasticity of the remaining air had been so far diminished that it was not able to force open the leather valves. He opened the exhaust valves by a plug, pushed in by hand, and the discharge valve was opened by a small pump placed on the outside, so that the valve opened into a void, instead of having to open against the pressure of the atmosphere.

It is supplemental proof of the neglect into which Guericke's work had fallen, to note that, in the middle of the 19th century, air-pumps constructed by Haas and Hurter including these identical contrivances were introduced with the claim that they were new inventions.

To modern eyes this air-pump of Guericke's may look crude and far from perfect; incapable of producing a high vacuum. However, the inventor proudly maintained that, when his pump was in good order, the rarefaction he obtained was so great that, when the stop-cock was opened and water was admitted, it filled the container so completely as to leave no more room than would accommodate a small pea.

Lest the modern student should be tempted to offer criticism of these naïve tests on the tacit assumption that approved standards, as of temperature, weight, size, etc. ought to have been employed, let him remember that no such standards were in existence. Without Guericke's

[9] Schott's "Technica Curiosa," pp. 68–70.

pioneer work there would have been no results to which such standards could now be applied or, at least, that someone would have had to rediscover all his original work at a later date. Now that atmospheric pressure is a commonplace, and the vacuum has a thousand applications it is hard to realize that there ever was a time when its discovery should have occasioned any comment. Today there is no mystery about it, but in Guericke's day it was a wonder to the thoughtful man and an ingenious deceit to the thoughtless. Yet the simplicity of the device by which he secured the vacuum can only leave us marvelling that it had remained so long to be discovered.

(To be concluded.)

THE FIRST GOVERNMENTAL APPLICATION OF PHOTOGRAPHY.

BY

DON D. NIBBELINK, A.R.P.S., A.P.S.A.*

Following the introduction of the photographic process of Daguerre by his physicist friend, Arago, before the two Academies des Sciences and des Beaux-Arts on August 19, 1839,[1] there resulted several instances which might conceivably be interpreted as governmental use of photography. However, the available literature has been rather vague as to which specific photographic application constituted the first time photography was utilized by any government.

Of the known instances, one or two seem to be logical possibilities on cursory examination. The first occurred in August, shortly after the photographic process of Daguerre was made public by a measure adopted by the Chamber of Deputies at the session of July 3, and by the Chamber of Peers, July 30, 1839. This consisted of sending Daguerrian images to various European sovereigns by the French Minister of Foreign Affairs.

The second incident occurred September 30, 1839, when King Friedrich Wilhelm III commanded Sachse, an art dealer from Berlin, to take a series of photographs of the Royal Park in his (the sovereign's) presence.

However, from the viewpoint of practical applications, both of these instances might be considered as acts more nearly akin to courtesy in the first instance, and curiosity in the second. Therefore, they should be largely disregarded as instances of governmental use of photography in favor of more substantiated claims.

The only other examples which merit serious consideration are: (1) The photographing of criminals by the Paris police in November, 1841, according to a contemporary newspaper account which stated that daguerreotypes were attached to the respective reports and "when set free and suspected of a new crime, the portrait is shown to all police officers, who soon seek out their man";[2] and (2) The daguerreotypes made by Edward Anthony,[3] who photographed the disputable location of certain highlands which figured prominently in the Northeastern boundary controversy between the United States and Great Britain.

As stated by the *New York Daily Tribune*,[4] " . . . Mr. Anthony, accordingly, took with him the necessary apparatus and plates, and

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produced satisfactory images of the hills, which were forwarded to the State Department. . . ." *

It was hoped that these daguerreotypes could be found in the National Archives since approximately seven and one-half linear feet of material concerning the Northeastern boundary between the United States and Canada had been received by the National Archives from the Department of State. Unfortunately, a recent search failed to locate these valuable records that would now be more than one hundred years old.

A MODERN REPRESENTATION OF EDWARD ANTHONY PHOTOGRAPHING THE MAINE-CANADIAN HIGHLANDS.

As closely as can be determined, these daguerreotypes were taken in October, 1840. Thus by chronological position and order of eventual importance, as the following paragraphs will show, this last example should be considered the first practical application of photography for any governmental purpose.

The detailed story behind the taking of these daguerreotypes is interesting from both a historical and adventurous standpoint as it

* This description was quoted from the *New York Daily Tribune* as the Edward Anthony obituaries found in the publications, "Anthony's Photographic Bulletin"[5] and "The Photographic Times,"[6] were seemingly taken from the previously available *Tribune* account which appeared the day after Anthony's death.

represents a portion in the development of our nation which was typified by the persistent courage of those men who were constantly endeavoring to expand America's political and economic boundaries."

The dispute between the United States and Great Britain, which eventually resulted in the Anthony daguerreotypes, began at the signing of the Treaty of Paris in 1783 and continued until the Webster-Ashburton Treaty of 1842.[7, 8, 9, 10]

Cornwallis surrendered his army at Yorktown October 18, 1781, but the tidings of the surrender did not reach England until the 25th of the following month. It was not until July 10, 1782, that even the first draft of the articles of peace was placed in the hands of Richard Oswald, one of the British secretaries of state. This slow progress of affairs was seemingly to typify the entire proceedings concerned with the settlement of the boundary dispute which dragged on for the ensuing sixty years.

The meeting to discuss terms of the peace was held in Paris. Appointed to represent the United States were Benjamin Franklin, John Jay, John Adams, and Henry Laurens. It is particularly interesting to note that of these representatives only Franklin was present during the initial negotiations, and it was he who prepared the first draft of the treaty that was taken to England before the arrival of the other representatives. In spite of Franklin's commendable intentions that the treaty negotiations be commenced without undue delay, it was natural that the remainder of the diplomats should insist on a revision of the articles of peace which would meet with their entire approval. Accordingly, a new draft was prepared by Jay, which, on final analysis, however, was on lines similar to that of the original.

The treaty was finally signed September 3, 1783. England, of course, readily agreed that complete independence was to be granted to the thirteen colonies, and topographical landmarks were specified which were to delineate the boundary between Canada and the United States.

All of the parties involved were undoubtedly aware that there existed much opportunity for disagreement on the actual location of the boundary, and incorporated into the treaty a statement which had sufficient bearing on subsequent events that it warrants quotation in full.

" . . . And that all disputes which might arise in future, on the subject of the boundaries of the United States may be prevented, it is hereby agreed and declared that the following are and shall be the boundaries. . . ."

The portion of the treaty which immediately followed contains the phrases probably originated by Franklin and penned by Jay which were the basis of the dispute in a very serious international controversy, which in its course saw a bloodless Aroostook War rise and abate, and which also resulted in the first governmental photographs, the Anthony daguerreotypes.

The northern boundary was described: "from the northwest angle of Nova Scotia, viz., that angle which is formed by a line drawn due north from the source of the St. Croix River to the Highlands; along the said Highlands which divide those rivers that empty themselves into the river St. Lawrence from those which fall into the Atlantic Ocean, to the northwesternmost head of the Connecticut River." The description of the eastern boundary also heavily emphasized the importance of "The aforesaid Highlands."

The treaty provided for the appointment of three commissioners to determine any disputable portions of the Maine-Canadian boundary. But, as became more evident as time went on, these commissioners neither established satisfactorily the location of the highlands, the source of the St. Croix River, the boundary in Passamaquoddy Bay into which the St. Croix empties, nor the location of the 45th parallel; all important considerations which subsequently arose in the dispute between the two countries.

Surveys and counter surveys were made by both the British and the Americans, each faction naturally endeavoring to retain as much of the disputed territory as possible. Thus the location of the highlands became very flexible and even illusive in nature.

The situation became hopelessly deadlocked and the boundary matters went largely unnoticed until approximately 1826, even though negotiations were understood to be still in progress.

Matters were once again brought to the fore and were further complicated when a United States citizen, one John Baker, was arrested by New Brunswick officials for raising, and refusing to lower, an American flag on what he thought was property in the State of Maine, but which the New Brunswick officials declared Canadian soil. Baker was fined and imprisoned for more than a year, in spite of efforts on the part of President Adams to have him released.

Still later, in 1829, the boundary differences were referred to the King of the Netherlands for impartial deliberation, but even though this monarch required exactly two years to prepare and announce his decision, the United States Senate advised the President to decline his Majesty's suggestions.

Closely following these events was the climax of the entire controversy—the bloodless Aroostook War. Complaints were constantly being received by both Maine and New Brunswick authorities that trespassers were encroaching on public lands and cutting valuable timber. The citizens of Maine became so enraged that volunteers rushed to the disputed area, taking with them some of the muskets which had been used at Valley Forge. The governor of Maine added to this number by drafting a thousand men, and shortly afterwards this was increased by an order from Adjutant General Thompson who ordered more than ten thousand men and officers to be ready to fight.

The entire nation became so aroused that the President was empowered to use ten million dollars and to call fifty thousand volunteers if the actual need arose. Fortunately, this was not necessary and the troops who had been stationed at the boundary were withdrawn after a temporary agreement had been reached providing against the possibility of future depredations.

Tired of the many years of disagreement, the Congress of the United States made two more appropriations, $25,000 and $75,000, to outfit and send a party of three commissioners and their aides to explore further and survey the disputed region. The commissioners, appointed by President Van Buren in 1840, were James Renwick, James Graham, and Andrew Talcott.[11]

James Renwick,[12] well known in engineering and educational circles, was lecturing at Columbia University at the time of Edward Anthony's graduation from the same school in 1838. He doubtlessly was acquainted with Anthony as a student in his classes, and so it was natural that he should call on Anthony to accompany him on the survey in 1840, particularly since at the time Anthony was engaged in the field of civil engineering as a surveyor on the Croton Aqueduct project.[13] Also, since his graduation, Anthony had acquired a proficiency in the art of daguerreotypy, studying under the well-known painter and artist, Professor Samuel F. B. Morse (he had yet to achieve fame as the inventor of the telegraph).[14]

"Anthony's Photographic Bulletin" [15] states: "Professor Renwick concluded that this knowledge of the daguerreotype might be put to good use on the survey, as England had denied the existence of any 'high lands' along the line, as had been claimed by the United States." And again in a later issue of the same publication:[16] "When the surveying party was fitted out, Mr. Anthony determined to take his camera along with him, and bring back if possible visible proofs of the highlands, if any were to be found."

Each of the commissioners had his own portion of the boundary to explore and to survey. Renwick and the party under his direction which included Anthony as an assistant engineer, at a rate of three or four dollars a day, departed in small groups from Portland, Maine, on the 26th and the 27th of August, 1840.[15] They met at the predetermined location of Woodstock on September 3rd, but unfortunately were forced to continue on from there without the benefit of a reliable barometer which was to have been furnished to the expedition by the authorities of the state. The lack of this instrument was so serious that one engineer was left behind in what ultimately proved to be a vain attempt to obtain another barometer. It is interesting to note that the *New York Daily Tribune* [4] later reported somewhat enthusiastically that "the testimony of the daguerreotype could not be controverted, however they might dispute that of the barometer and the spirit level."

From the very outset the expedition was beset with delays and burdened with such hardships that it was not until the 22nd of September that the line to be explored was reached, and even then the season had advanced to a point where efficient work was not practicable. No one in the party was familiar with the territory to be transversed and explored, and no competent guides could be found. After exhaustive inquiry, an Indian was located who knew of a single path in the general direction the explorers wished to take, but even this route held little promise of yielding any results on the object of the commission. The Indian, however, in want of someone better, was hired for the job.

The most practical way of penetrating this uninhabited wilderness and transporting the necessary provisions was by canoe. Even this transportation method undoubtedly had to be supplemented by packing the equipment on the backs of members of the expedition. To add to these discomforts were a rapidly dimishing food supply and the fact that Renwick's party had been directed to explore a portion of the line which was obviously within the acknowledged territorial limits of Britain. Thus their presence could have been easily interpreted as trespassing by those not acquainted with the purpose of the survey.

Fortunately, a summation of the work of the four detachments into which Renwick had divided his men, showed that a large portion of the dividing ridge had been explored. Although an attempt was made to secure as much information about the area as possible in the time which remained, the work was brought to a close by a heavy snowstorm on the 12th of October.

The joint report of the three commissioners which was presented January 6, 1841,[15] to John Forsyth, Secretary of State, said that "strong grounds exist for the belief that its (the highland's) summits are not only higher than any point which has been measured, but that, although cut by the Rimouski (River), it exceeds in average elevation any part of the disputed territory."

Thus the long search for the illusive highlands was over. The home-made camera of Edward Anthony was probably set up on a convenient boulder or stump or surveyor's tripod, and the epochal exposures were made sometime in the early part of October, 1840. "These," Mr. Anthony is reported as having said with some pardonable satisfaction,[16] "were the first sun pictures ever obtained by a scientific government expedition."

Although some additional work on the boundary was necessary,[17] the foundation had been laid and the United States and Great Britain began a series of negotiations through their respective representatives, Daniel Webster and Lord Ashburton. With the differences settled between the two great countries, the way to peace and prosperous trade relations was finally reached through the ratification of the Ashburton treaty by a vote of nine nays to thirty-nine yeas, August 20, 1842.

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Magnesium Production Started by Mathieson.—(*Refrigerating Engineering*, Vol. 46, No. 1.) Production of magnesium metal at the newly erected magnesium-chlorine plant in Louisiana has begun, according to an announcement by the Mathieson Alkali Works, Inc., the operating company. The plant is owned by the Defense Plant Corporation and has a future capacity of more than 50,000,000 lb. of magnesium metal a year. The design and engineering of this project are said to be unique, and it is the only plant of its type in operation. The principal raw material is dolomitic stone, a rock resembling limestone and consisting of calcium and magnesium carbonates which is shipped from nearby quarries. This ore is calcined, locally produced natural gas being used for the purpose. The resulting oxides of calcium and magnesium are treated with calcium chloride, a product of the process by which soda ash is made at the parent Mathieson plant in Louisiana. The mass is then treated with carbon dioxide obtained from the calcination of the dolomite, which converts the calcium into insoluble carbonate, leaving magnesium chloride. This product, after being concentrated, is electrolyzed, forming magnesium and chlorine. Magnesium metal in this plant is manufactured by a new process developed by Mathieson engineers which produces not only pure magnesium metal but also liquid chlorine, both of which are highly essential to the war effort. It is estimated when running at full production, that this project will employ approximately 1,000 workers.

R. H. O.

An Optimistic Angle on Oil Reserves.—DORSEY HAGER. (*The Oil Weekly*, Vol. 110, No. 8.) Much is being written and discussed about the oil possibilities of the United States now that another period of scarcity is forecast as just around the corner. Our crude oil reserves are being drawn upon, drilling has declined, and new oil must be sought, but there is no immediate cause for alarm, nor should oil operators be stampeded into drilling thousands of unnecessary dry holes. There still remains much favorable area for prospecting. New activities are now justified in all the outlying areas lightly passed by when the prolific East Texas and West Texas fields were opened. Oil producers all hope to find another East Texas. Even though many new oil fields are not found, there is no need to worry, since plenty of oil is locked up in our oil shale beds, in outcropping tar sands, and in lignite and coal beds. Perhaps we will draw on South American crude oil resources first to augment our failing reserves, but once the war is over, if many new North American oil fields are not found before then, several billion dollars will be allocated for the mining of oil shale and for the development of oil from coal, so there will be no lack of oil products, nor no need to fear a shortage of oil products in the future. However, there is every reason to believe that we still have important untapped oil reserves that will be found after an intensive search has been undertaken, and it is too early to become pessimistic if history conveys any significance, as all the earlier predictions of shortage proved fallacious. Only an intensive drilling campaign will supply the answer.

R. H. O.

ON THE FORCED VIBRATIONS OF NON-LINEAR SPRINGS.

BY

C. R. WYLIE, JR.

Introduction: As Prof. von Kármán pointed out so vividly in his Gibbs Memorial Lecture "The Engineer Grapples with Non-Linear Problems" (1),* current engineering research is confronting applied mathematicians more and more frequently with intrinsically non-linear problems, that is, with problems which lose their essential meaning if an approximate linearization is attempted. Among the most simple of these problems is that of determining the amplitude of the forced vibrations of a non-linear spring. This question has been discussed both from an experimental (2) (3) and from a theoretical (2) (4) (5) (6) point of view in a number of papers. It is also considered in texts on the theory of vibration (7) (8). Yet in spite of this attention, the problem seems to the author to be but incompletely solved from the standpoint, say, of the designer who may occasionally encounter it.

The present note is a quantitative study of the problem, and consists of a comparison of several methods of approximate solution in relation to accurate solutions obtained by numerical integration. One of these methods, which incidentally seems to be of rather wide applicability to problems formulated in terms of non-linear differential equations, or differential equations with periodic coefficients, is found to be of high accuracy over most of the range of the parameters of the problem, and admits, moreover, of a simple graphical representation. This is given in the form of a pair of nomograms which constitute a reasonably complete numerical solution of the problem.

(I) We are specifically concerned with the determination of the amplitude of the undamped vibrations of a mass M excited by a periodic force $Q \cos wt$ and restrained by a spring whose elastic law is embodied in the non-linear relation $F = -P^2 s - Cs^3$. Our physical assumption is that the response of the mass to the impressed force is of the same frequency, and is either in phase with it or precisely 180 degrees out of phase. In mathematical form our problem is to solve the differential equation

$$Ms'' + P^2 s + Cs^3 = Q \cos wt \tag{1}$$

subject to the conditions $s'(o) = 0$, $s\left(\frac{\pi}{2w}\right) = 0$.

Any attempt at a practical numerical solution must clearly involve a reduction in the number of parameters appearing in the equation (1).

* Numbers in parentheses refer to the bibliography at the end of the paper.

Hence we put

$$(2) \qquad x = wt, \qquad y = \frac{P^2 s}{Q}, \qquad a = \frac{CQ^2}{P^6}, \qquad \lambda^2 = \frac{Mw^2}{P^2},$$

so that (1) becomes

$$(3) \qquad \lambda^2 y'' + y + ay^3 = \cos x$$

subject to the conditions $y'(o) = 0$, $y\left(\frac{\pi}{2}\right) = 0$. It is easy to verify that each of the combinations appearing in (2) is dimensionless. Henceforth we shall deal exclusively with the dimensionless formulation (3) and shall investigate the dependence of y_{max} (which, to make a natural extension of a familiar phrase, might be called the *magnification ratio*) upon the two dimensionless parameters λ and a.

(II) In order to have accurate results with which to compare the approximations obtained by the various methods to be considered, a number of solutions of (3) were plotted by numerical integration. From these a series of curves of y_{max} versus λ were drawn for various values of a from -1 to 1. These are shown in Fig. 1.

Many methods are available for the numerical solution of (3), all of them highly laborious since the boundary conditions involved do not both pertain to the same end of the range under consideration. Thus to determine a single solution it was necessary under the best of circumstances to carry the process through for two distinct values of y_0, interpolating between them on the basis of the values of $y_{\pi/2}$ to which they gave rise, and to check this corrected value of y_0 by a third integration.

The integration process finally adopted was a nameless one, apparently little known, presented in Levy and Baggott (9), where it is recommended for second order differential equations in which the first derivative does not appear. It consists simply of repeated applications of the formula

$$(4) \qquad y_{n+1} = 2y_n - y_{n-1} + h^2 \left\{ y''_n + \frac{1}{12} \Delta^2 y''_{n-1} \right\},$$

where h is the difference between consecutive values of the independent variable, and Δ^2 is the usual second difference symbol. It is easily derived from the Newton-Stirling interpolation formula, and in the "open" form above involves an error of $-\frac{h^5 y^{(5)}}{12}$. It requires the preliminary determination of but three values of y, which in the present instance can be taken as y_{-1}, y_0, and y_1, involving thus but one calculation, since from symmetry $y_{-1} = y_1$.

The results of this numerical analysis are quite surprising in at least one respect since they reveal that the in-phase amplitude curves for

$a > 0$ consist not of a single branch as usually assumed * but of two (referred to hereafter simply as branch I and branch II) representing two distinct types of in-phase vibration. The first exists only for small values of λ, and departs notably from a simple wave form like the cosine curve. In fact its extreme values may occur at $x = \frac{\pi}{4}$ or even more.

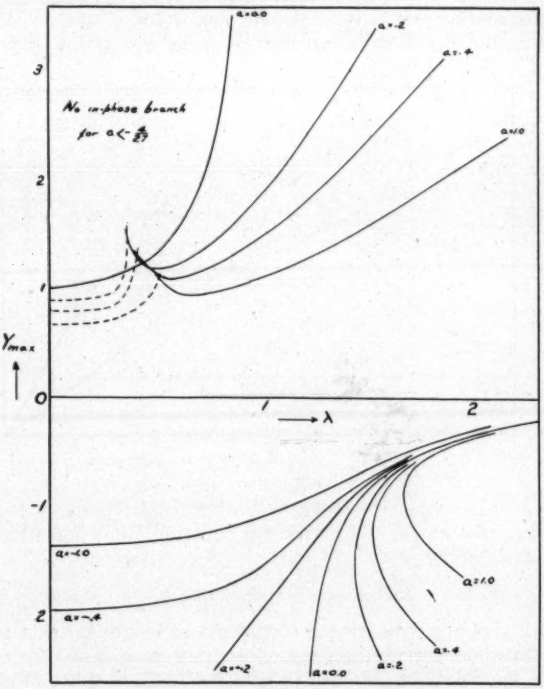

FIG. 1.

Solutions of this type for $a = 1$ are shown in Fig. 2. The second type of solution overlaps the range of the first a little and exists for all larger values of λ. Its form is that of a simple wave with its maximum value always at $x = 0$. From Fig. 1 it appears that in the immediate vicinity of the intersection of these two branches each rises sharply, giving rise to what might be called a sort of pseudo-resonance.

* See for example Fig. 90, p. 140, in reference (7) or Fig. 261, p. 405, in reference (8).

Although but a single in-phase amplitude curve exists for $a < 0$, and then only if $a > -\frac{4}{27}$, these curves represent, over part of their extent, vibrations of the first type noted above, i.e. vibrations whose maxima occur elsewhere than at $x = 0$. In Fig. 1 such portions of all amplitude curves are shown as broken lines.

(III) The simplest and most natural method of obtaining an approximate solution of (3) is to assume $y = A \cos x$, and require that the differential equation be satisfied at some one point, say at the

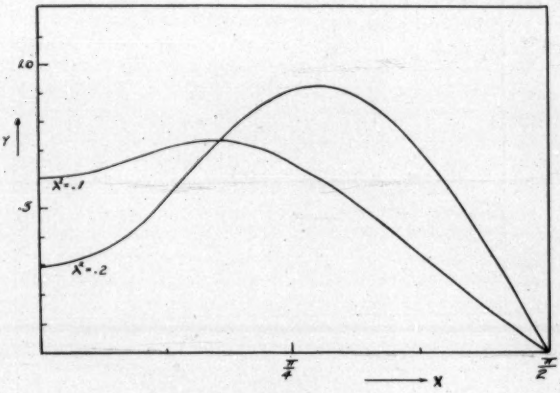

FIG. 2.

extremum where $x = 0$. This yields at once the following cubic equation for A

$$aA^3 + (1 - \lambda^2)A - 1 = 0. \tag{5}$$

This method of approximation is considered at length in texts such as (7) and (8) where curves of $A(= y_{max})$ are drawn against λ for various values of a. Solutions obtained by this method are quite inaccurate and moreover descriptively incorrect as may be seen in Fig. 3 where the results of various approximate methods are compared with the actual graph of y_{max} versus λ, $(a = 1)$, as obtained by numerical integration.

(IV) The natural extension of this method, as pointed out by Den Hartog (4), consists in assuming $y = A \cos x + B \cos 3x$ and determining A and B so that equation (3) is satisfied at two values of x, say at $x = 0$ and $x = \frac{\pi}{4}$. If we do this we obtain without difficulty the pair

of equations

$$a(A + B)^3 + (A + B) - 9\lambda^2(A + B) + 8\lambda^2 A - 1 = 0,$$
$$\tfrac{1}{2}a(A - B)^3 + (A - B) - 9\lambda^2(A - B) + 8\lambda^2 A - 1 = 0.$$

Since y_{max} will normally equal $(A + B)$ it is natural to rewrite these

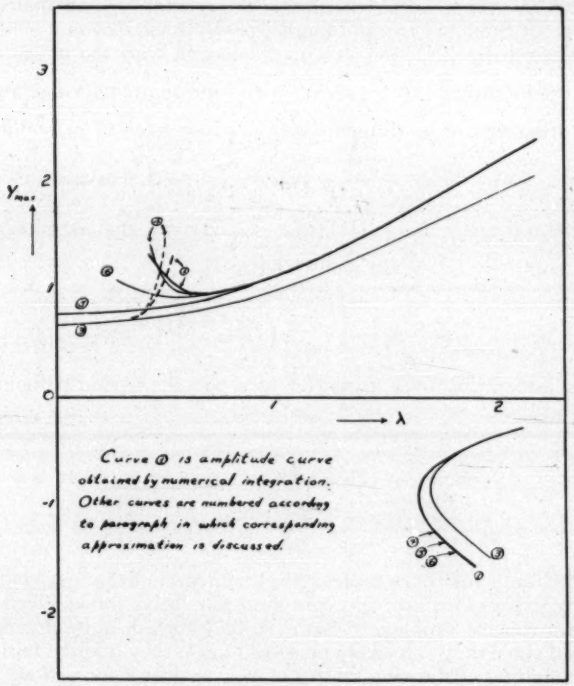

FIG. 3.

equations letting $(A + B) = S$ and $(A - B) = T$, so that

$$aS^3 + S(1 - 5\lambda^2) + 4\lambda^2 T - 1 = 0, \tag{6}$$
$$\tfrac{1}{2}aT^3 + 4\lambda^2 S + T(1 - 5\lambda^2) - 1 = 0.$$

This system of equations is rather difficult to solve unless a reasonably good preliminary estimate of S and T is known. However the values of S $(= y_{max})$ as here determined check very well with the actual values. In addition, the curve of y_{max} versus λ is descriptively accurate in this

case, exhibiting clearly the unexpected phenomenon of two types of in-phase solutions. All this is displayed in Fig. 3.

Extending this method by assuming $y = A \cos x + B \cos 3x + C \cos 5x \ldots$ etc. leads to algebraic equations in A, B, $C \ldots$ far too complicated for computational purposes, and seems to the writer to be of no practical value as a method of approximation.

(V) A third method of solution, of the general type associated with the name of Stodola (10) and more recently suggested in a somewhat modified form by Rauscher (11) in connection with the present problem, is the following. If we set $y'' = v\dfrac{dv}{dy}$ in equation (3) and integrate the resulting first order differential equation from y_0 to y, we obtain

$$\tfrac{1}{2}\lambda^2 v = \tfrac{1}{2}(y_0^2 - y^2) + \tfrac{1}{4}a(y_0^4 - y^4) + \int_{y_0}^{y} \cos x dx.$$

If we assume again, as in (III), that $y = y_0 \cos x$, the last integral becomes simply $\dfrac{1}{2y_0}(y^2 - y_0^2)$ and we have

$$\lambda v = \lambda \frac{dy}{dx} = -\sqrt{(y_0^2 - y^2)\left(\frac{ay_0^3 + 2y_0 - 2}{2y_0} + \frac{ay^2}{2}\right)};$$

whence, integrating over a quarter of a period, we find without difficulty that

$$(7.1) \qquad \frac{\pi}{2} = \lambda \sqrt{\frac{y_0}{ay_0^3 + y_0 - 1}}\, K\left\{\sqrt{\frac{ay_0^3}{2(ay_0^3 + y_0 - 1)}}\right\}, \quad a > 0,$$

$$(7.2) \qquad \frac{\pi}{2} = \lambda \sqrt{\frac{2y_0}{ay_0^3 + 2y_0 - 2}}\, K\left\{\sqrt{\frac{ay_0^3}{2 - 2y_0 - ay_0^3}}\right\}, \quad a < 0,$$

where K stands for the complete elliptic integral of the first kind.

These expressions are very complicated to solve for y_0, given a and λ, as in a specific problem. However they furnish quite accurate results, and since they can easily be solved for λ, they afford a fairly convenient method of drawing curves of y_{max} against λ for various values of a. Since this method is premised upon the assumption that $y = y_0 \cos x$ as a first approximation, it is clear that it cannot possibly disclose the existence of solutions of the type giving rise to branch I of the actual amplitude curves.

(VI) A final method of approximation which the author believes to be new, at least in the present application, consists in approximating the term $\cos x$ in equation (3) in such a way that the modified equation can be solved exactly. Two things guide us in our choice of an approximating function: First, equation (3) with the cosine term deleted can be solved exactly in terms of elliptic functions; second, the elliptic

function $A\ cn(u)$ * is periodic with real period $4K(k)$ (where K is the complete elliptic integral of the first kind, and k is the modulus of cnu), and hence $A\ cn\left\{\frac{2Kx}{\pi}\right\}$ is of period 2π for any value of the modulus k, and so corresponds qualitatively to $\cos x$.

To make this correspondence more precise we require that

$$\int_0^{\pi/2} A\ cn\left\{\frac{2Kx}{\pi}\right\} dx = \int_0^{\pi/2} \cos x dx = 1.$$

Integrating we have

$$\frac{A\pi \sin^{-1}}{2Kk}\left(sn\left\{\frac{2Kx}{\pi}\right\}\right)\Big|_0^{\pi/2} = 1$$

or, since $sn(o) = 0$ and $sn(K) = 1$,

$$A = \frac{2kK}{\pi \sin^{-1} k}. \tag{8}$$

We now consider the modified equation

$$\lambda^2 y'' + y + ay^3 = \frac{2kK}{\pi \sin^{-1} k} \cdot cn\left\{\frac{2Kx}{\pi}\right\}, \quad (k \text{ arbitrary}), \tag{3.1}$$

and try $y = y_0\ cn\left\{\frac{2kx}{\pi}\right\}$ as a solution. Clearly $y'(0) = 0$ and $y\left(\frac{\pi}{2}\right) = 0$ as the boundary conditions require, and it remains to determine y_0 and k so that equation (3.1) is identically satisfied.

Now it is easy to verify that for $y = y_0\ cn\left\{\frac{2Kx}{\pi}\right\}$

$$\frac{d^2y}{dx^2} = -y_0\ cn\left\{\frac{2Kx}{\pi}\right\}\left[(1 - 2k^2) + 2k^2\ cn^2\left\{\frac{2Kx}{\pi}\right\}\right]\left(\frac{2K}{\pi}\right)^2$$
$$= (2k^2 - 1)\left(\frac{2K}{\pi}\right)^2 y - 2\left(\frac{2kK}{\pi y_0}\right)^2 y^3.$$

Hence to satisfy (3.1) we require

$$\lambda^2\left\{(2k^2 - 1)\left(\frac{2K}{\pi}\right) y - 2\left(\frac{2kK}{\pi y_0}\right)^2 y^3\right\} + y + ay = \frac{2kK}{\pi \sin^{-1} k}\frac{y}{y_0}$$

or, equating to zero the coefficients of y and y^3,

$$1 + \lambda^2(2k^2 - 1)\left(\frac{2K}{\pi}\right)^2 = \frac{2kK}{\pi y_0 \sin^{-1} k} \quad \text{and} \quad a = 2\lambda^2\left(\frac{2kK}{\pi y_0}\right)^2.$$

* For an exposition of the properties of the elliptic functions cosine-amplitude and sine-amplitude see, for example, Hancock (12).

From these we obtain finally

$$y_0 = \lambda \sqrt{\frac{2}{a}} \frac{2kK}{\pi}, \tag{9}$$

$$1 + \lambda^2(2k^2 - 1)\left(\frac{2K}{\pi}\right)^2 = \frac{1}{\lambda}\sqrt{\frac{a}{2}}\frac{1}{\sin^{-1} k}. \tag{10}$$

Equation (10) involves the single unknown k, which when determined and substituted in (9) yields the required amplitude, y_0. The accuracy of this method is high, as is illustrated in Fig. 3, except for small values of λ, for which like the methods of (III) and (V) it fails to reveal branch I of the amplitude curve.

From equation (9) it is clear that here, as in the method of (V), a separate treatment is required for the case $a < 0$. Accordingly we now replace the term $\cos x$ in equation (3) by $A\ sn\left\{\frac{2Kx}{\pi} + K\right\}$, where as before to insure a satisfactory degree of approximation we require

$$\int_0^{\pi/2} A\ sn\left\{\frac{2Kx}{\pi} + K\right\} dx = \int_0^{\pi/2} \cos x dx = 1.$$

This gives at once

$$\frac{\pi A}{2kK}\left[\cosh^{-1}\left\{\frac{dn\left(\frac{2Kx}{\pi} + K\right)}{\sqrt{1 - k^2}}\right\}\right]_0^{\pi/2} = 1$$

or

$$A = \frac{2kK}{\pi} \cdot \frac{1}{\cosh^{-1}\frac{1}{\sqrt{1 - k^2}}}. \tag{11}$$

We now propose $y = y_0\, sn\left\{\frac{2Kx}{\pi} + K\right\}$ as a solution of the modified equation

$$\lambda^2 y'' + y - ay^3 = \frac{2kK}{\pi} \frac{1}{\cosh^{-1}\frac{1}{\sqrt{1 - k^2}}} sn\left\{\frac{2Kx}{\pi} + K\right\}, \quad a > 0. \tag{3.2}$$

It is easy to verify that in this case

$$\frac{d^2y}{dx^2} = -\left(\frac{2K}{\pi}\right)^2 (1 + k^2)y + \left(\frac{2kK}{\pi y_0}\right)^2 2y^3;$$

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hence to satisfy (3.2) identically, requires ultimately that

$$y_0 = \lambda \sqrt{\frac{2}{a}} \frac{2kK}{\pi} \tag{12}$$

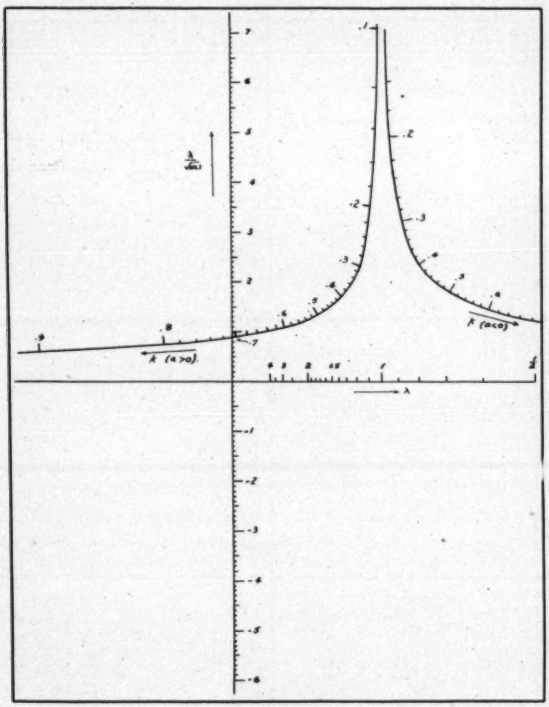

FIG. 4.

and

$$1 - \lambda^2(1 + k^2)\left(\frac{2K}{\pi}\right)^2 = \frac{1}{\lambda}\sqrt{\frac{a}{2}} \frac{1}{\cosh^{-1}\frac{1}{\sqrt{1 - k^2}}}. \tag{13}$$

From (13) the value of k can be found and hence the amplitude y_0 can easily be found from (12). The accuracy of this determination is in the neighborhood of $\frac{1}{2}$ of 1 per cent. for $k < .8$.

Equations (10) and (13) are difficult to solve as they stand, but from a practical point of view this complexity is illusory for each admits of a simple nomographic solution. Moreover equations (9) and (12)

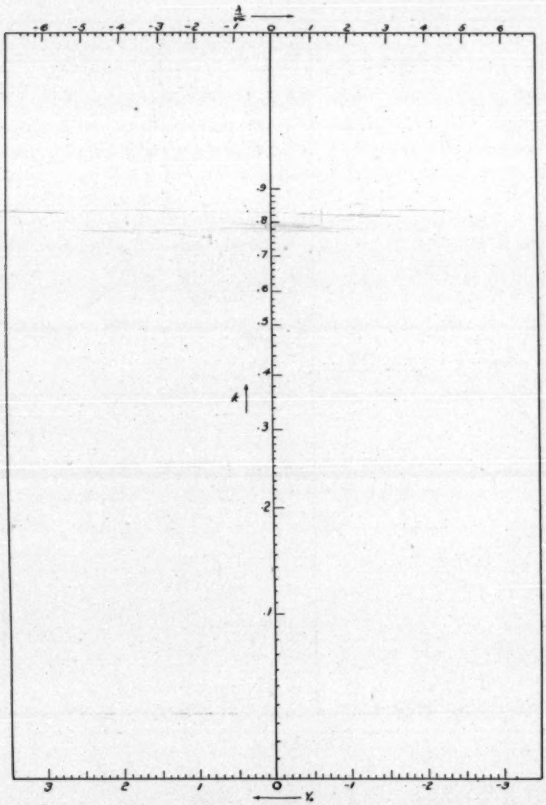

FIG. 5.

(which are identical) can likewise be exhibited as nomograms. To accomplish this it is necessary to take as the parameters upon which y_0 depends, not λ, a, and k, but λ, $\frac{\lambda}{\sqrt{a}}$, and k. We then have without

difficulty from (9), (10) and (13)

$$(9.1)\qquad \begin{vmatrix} -y_0 & 1 & 1 \\ \dfrac{\lambda}{\sqrt{a}} & \tfrac{1}{2} & 1 \\ 0 & \dfrac{1}{1+\dfrac{\pi}{2\sqrt{2k}K}} & 1 \end{vmatrix} = 0,$$

$$(10.1)\qquad \begin{vmatrix} (1-2k^2)\left(\dfrac{2K}{\pi}\right)^2 & \dfrac{1}{\sqrt{2}\sin^{-1}k} & 1 \\ \dfrac{1}{\lambda} & 0 & 1 \\ 0 & \dfrac{\lambda}{\sqrt{a}} & 1 \end{vmatrix} = 0,$$

$$(11.1)\qquad \begin{vmatrix} (1+k^2)\left(\dfrac{2K}{\pi}\right)^2 & \dfrac{1}{\sqrt{2}\cosh^{-1}\left\{\dfrac{1}{\sqrt{1-k^2}}\right\}} & 1 \\ \dfrac{1}{\lambda} & 0 & 1 \\ 0 & \dfrac{\lambda}{\sqrt{a}} & 1 \end{vmatrix} = 0.$$

The nomograms corresponding to (10.1) and (11.1) appear in Fig. 4, and that corresponding to (9.1) appears in Fig. 5.

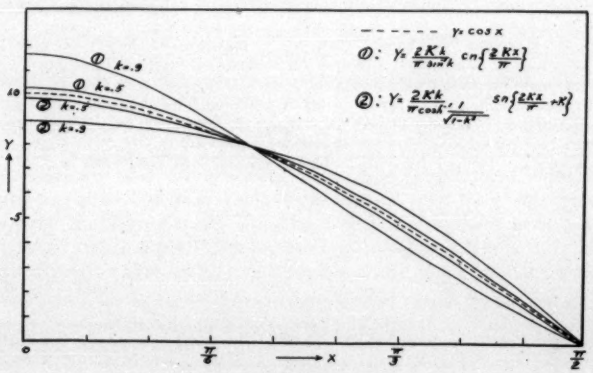

FIG. 6.

The method of the present paragraph appears promising in connection with other non-linear problems, and as a possible guide in making such applications Fig. 6 is included to show the degree to which $A\ cn\ 2Kx$ and $A\ sn\ 2Kx$, K subject to (8) and (11) respectively, approximate $\cos x$. The total range of k is from 0 (when each function reduces to $\cos x$) to 1. From the figure it is clear that even as near the end of the range as k .9 the two functions represent $\cos x$ reasonably well. Moreover it is probably unwarranted in many physical applications to insist that the impressed vibratory force is rigorously expressed by a term of the form $\cos x$, and it might well be argued that in a number of cases the forcing function could legitimately be taken *ab initio* as $A\ cn\left\{\frac{2Kx}{\pi}\right\}$ or $A\ sn\left\{\frac{2Kx}{\pi}+K\right\}$ (or numerous others for that matter). From this point of view the degree of approximation achieved by this last method becomes even greater.

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SOME PRELIMINARY INVESTIGATIONS ON DEHYDRATION OF FRUITS AND VEGETABLES WITH INFRARED ENERGY.[1]

BY

JOHN E. NICHOLAS.[2]

Recent studies [3] carried for two successive years with infrared electric lamps indicate that seeds can be dried by infrared radiant energy to a safe storage condition. This suggests the possibility of applying the principle to dehydration of fruits and vegetables.

Many fruits and vegetables used in our daily diet are successfully grown and stored for future use by individual families. Established practices in food preservation by canning or various ways of drying are generally known. The use of electric radiant energy offers advantages in ease of control and probable speed of drying.

The drying of fruits and vegetables requires the removal of large quantities of water, thus reducing weight and bulk of food, hence smaller storage space.

In any process of food preservation, it is difficult to retain all of the original quality, vitamins, color and flavor. Usually the shorter the time of the preservation process, the smaller the loss of original quality. Both of these rules have special application to drying.

Electrical energy in the form of infrared heat offers a convenient and flexible method of dehydration in that a suitable degree of heat both as to intensity and amount can be easily applied.

Figure 1 illustrates an experimental type, open structure dehydrator, using infrared drying lamps as a source of heat. The efficiency of drying by the infrared rays obtainable from this type of lamp is due in large part to the penetrating characteristics of the wave lengths of its radiation which are between 6,500 and 14,000 angstroms. The frame work is approximately 3 feet high and 5 feet wide, supporting twelve 250-watt infrared lamps, in 2 rows of 6 each, spaced 10 inches apart. Each row of lamps has a switch. The experimental drying trays are 9 inches square and 1 inch deep, made from galvanized window sash or wire screen. The tray rack, located half way between the lamps, supporting the drying trays, is made of No. 9 galvanized wire. At mid-point is an extra support to keep it from sagging when fully loaded. The rack is 8½ inches wide, reënforced between each tray and spans the

[1] Paper No. 1179 in the Journal Series of The Pennsylvania Agricultural Experiment Station which was authorized for publication on May 5, 1943.

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[3] John E. Nicholas and H. B. Musser, "Seed Drier Uses Infrared Electric Lamps." *Agricultural Engineering*, Vol. 22, No. 12, December, 1941.

whole width of the frame. The length of frame and rack is optional, depending on the number of lamps desired for drying.

The drying process is immediate; it begins as soon as the lamps are turned on. No preheating is necessary. The largest portion of the infrared rays travels directly through the materials to be dried, the remainder is directed by the reflector of the lamp. The open structure

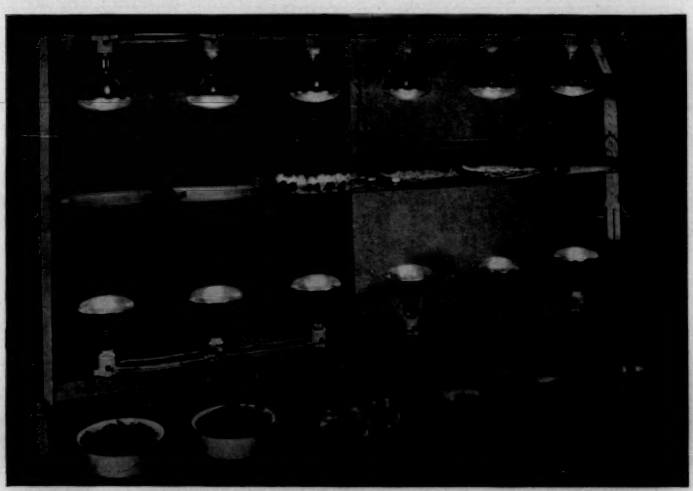

FIG. 1. Experimental open type fruit and vegetable dehydrator using infrared radiant energy as a heat source.

permits easy escape of water vapors. Since the infrared radiation penetrates into the material, the drying process proceeds throughout the material, consequently no enclosure is necessary to confine the heat.

INFRARED DRYING LAMPS.

Lamps are essentially simple sources of radiant energy, generating and emitting energy over definite ranges of wave-length and frequency.

The spectral region of wave-lengths between 3800 and 7200 angstroms is the visible spectrum produced by mazda lamps. Infrared drying lamps emit in the short-wave infrared region from the limit of the visible spectrum between 6500, the red light, to 50,000 angstroms. Wave-lengths longer than 50,000 are absorbed by the bulb and reradiated or carried away by convection. From 75 to 85 per cent. of the wattage input to a filament lamp is dissipated as heat through infrared radiation.

SPECTRAL ENERGY CURVES.

The energy distribution for a "black body" radiation at the absolute temperature T (Kelvin scale) is given by Planck's equation:

$$E_\lambda = \frac{C}{\lambda^5(e^{c/\lambda T} - 1)}. \quad (1)$$

E_λ is the radiant energy for wave-length λ, at the absolute temperature T, C and c are constants, and e the natural logarithmic base.

According to Wien's displacement law, there is a very definite relation between the wave-length corresponding to the maximum energy intensity in radiation from a black body at the Kelvin temperature T; that is

$$\lambda_m T = A, \text{ a constant.} \quad (2)$$

The maximum energy E_m, corresponding to λ_m, is given by

$$E_m = \frac{C}{\lambda_m{}^5(e^{c/\lambda_m T} - 1)}. \quad (3)$$

By substituting equation (2) in (3) and then dividing (1) by (3) we obtain

$$\frac{E_\lambda}{E_m} = \left(\frac{A}{\lambda T}\right)^5 (e^{c/A} - 1)(e^{c/\lambda T} - 1)^{-1}. \quad (4)^*$$

The values of the constants are:

$A = 2{,}890$ micron degrees,
$c = 14{,}350$ micron degrees.

Figure 2 shows the relative energy emission plotted against the wave-length in microns for a black body at 2570° Kelvin based on approximately the "color temperature" of a 250-watt, 115-volt, clear bulb drying lamp operating at an efficiency of 7.5 lumens per watt. The color temperature is the black body temperature radiating light of the same color as the light from the lamp. Although the spectral distribution of the radiation from a black body is not exactly the same as that of a tungsten or carbon filament at the same color temperature, the spectrum correspondence is very close in the visible region with but a slight difference in the infrared. While the absorption of the glass bulb of the lamp has some effect on the distribution of the infrared, and energy of wave-lengths longer than 4 microns are not all transmitted by the glass, for all practical purposes the slight differences are negligible and the similarity between a black body radiation and that of a tungsten filament lamp is sufficiently close.

* Miscellaneous Publications of the Bureau of Standards No. 56.

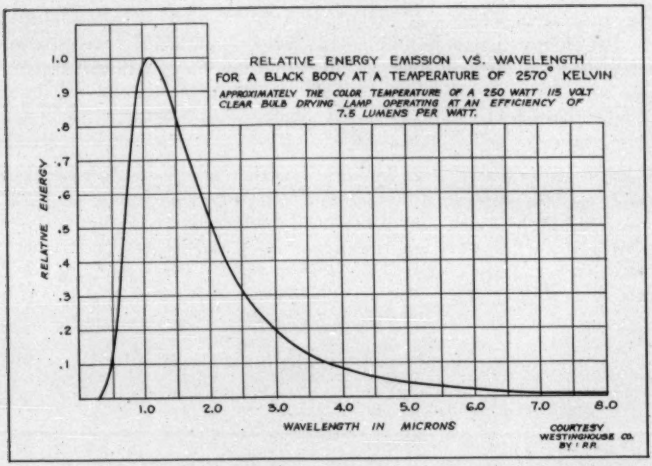

FIG. 2. The relative spectral energy distribution for a black body at 2570° Kelvin radiating approximately the color temperature of a 250 watt, 115 volt clear bulb drying lamp operating at an efficiency of 7.5 lumen per watts.

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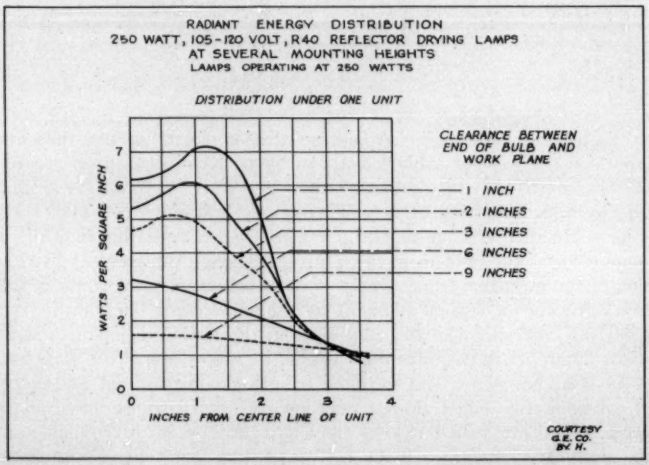

FIG. 3. Spectral distribution, watts per square inch emitted by a 250 watt, 105–120 volt, R-40 reflector drying lamp at several mounting heights vs. distances from the centre line of unit.

RADIANT ENERGY DISTRIBUTION AS A FUNCTION OF "MOUNTING HEIGHT" AND RADIAL DISTANCE FROM ITS CENTER OF SUSPENSION.

The total energy emitted by an incandescent source is proportional to the area included between the energy curve and the axis of the wavelength, λ. The intensity of the total radiation on various planes perpendicular to the axis of an infrared drying lamp is shown in Fig. 3, where the abscissa is the distance in inches from the axis of the unit, measured in the work plane indicated for each curve.

THE RATE OF DEHYDRATION.

When radiation falls on substances a portion is reflected, another absorbed, and if the matter is transparent or very thin a part is transmitted.

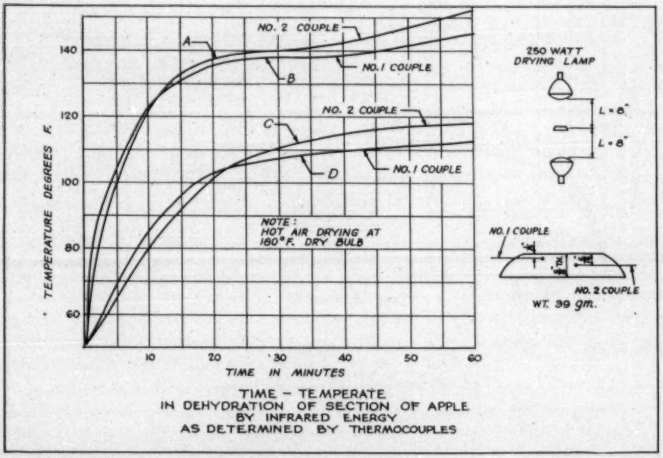

FIG. 4. Time-temperature relation in the dehydration of a $\frac{3}{8}$" thick piece of apple (approx. weight 39 gm.) by two 250 watt reflector type infrared drying lamps, 8" from drying plane as measured by thermocouples. No. 2, located on horizontal plane through center of piece, $\frac{3}{4}$" from edge curve *A*, and No. 1 on a parallel plane, $\frac{1}{4}$" from top surfaces also $\frac{3}{4}$" from edge, curve *B*. Curves *C* and *D* are for a similar piece dehydrated at 180° F. dry bulb air temperature in a "convection type" dehydrator.

In order to measure radiation it is converted into heat by absorption in matter, and the heat is then measured by the temperature changes which it produces. For all practical purposes this can most conveniently be attained by thermocouples.

The entire phenomenon of radiant energy absorption is complex, therefore only certain pertinent and relative values can be measured.

In dehydration of any kind of material the problem presents many variables, such as color, thickness, consistencies, distribution and quality.

Figure 4, curves *A* and *B* show the rate of drying of a piece of fresh apple (Baldwin); $\frac{5}{8}$ inches thick, weighing 39 gm. before dehydration. Couple No. 1, curve *B*, is $\frac{1}{8}''$ below the top horizontal plane, $\frac{3}{4}''$ from edge and couple No. 2 on central horizontal plane at equal depth from the edge. The distance *L*, to the drying plane, is 8 inches. Curves *C* and *D* are comparable rates of dehydration of a similar piece in a "convection type" drier with a 180° F. dry bulb air temperature.

Figure 5 is the time-temperature relation in the dehydration of pieces of apple, $\frac{5}{8}''$ thick (approx. wt. 40 gm.) by two-250 watt, reflector

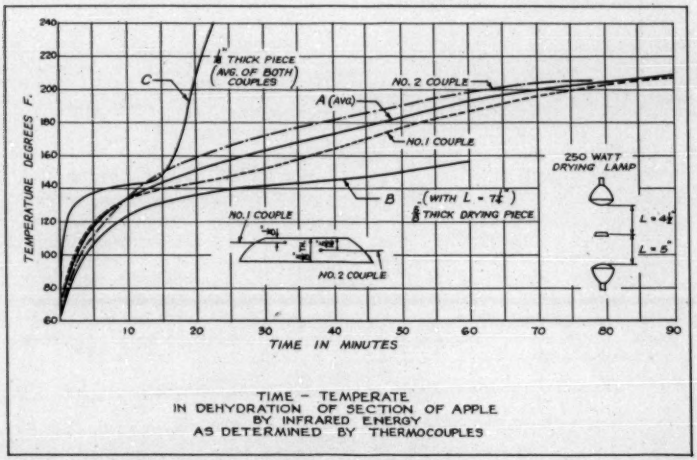

FIG. 5. Time-temperature relation in the dehydration of pieces of apple, $\frac{5}{8}''$ thick, (approx. wt. 40 gm.) by two-250 watt, reflector type drying lamps. Curve *A* average of couples 1 and 2 drying plane $4\frac{1}{2}''$ and 5" from lamps; curve *B*, with drying plane $7\frac{1}{4}''$ from lamps; and curve *C* for a piece only $\frac{1}{16}''$ thick (wt. 8 gm.) with lamps $4\frac{1}{2}''$ and 5" from drying plane.

type drying lamps. Curve *A* average of couples 1 and 2 drying plane $4\frac{1}{2}''$ and 5" from lamps; curve *B*, with drying plane $7\frac{1}{4}''$ from lamps; and curve *C* for a piece only $\frac{1}{16}''$ thick (wt. 8 gm.) with lamps $4\frac{1}{2}$ and 5" from drying plane.

When the thickness of the drying piece was reduced to $\frac{1}{16}$ inch, and the drying plane remained at $4\frac{1}{2}''$ and 5" from the lamps, the average of couples 1 and 2 is shown by curve *C*. The temperatures measured by couples 1 and 2 (average curve *A*) Fig. 5, cross at the interval of 10 minutes after which the center of the apple is warmer and continues so for nearly 90 additional minutes.

A similar crossing of the temperature curves is shown in Fig. 4, curves *A*, *B* and *C*, *D* indicating a gradient from the center toward the outer surfaces.

Table 1 gives a portion of experimental data on loss in weight for two different materials when dried by infrared drying lamps located 8″ from the drying plane (as shown in Fig. 4, curves *A* and *B*). The apples

TABLE 1.

Some Experimental Data on Sliced ($\frac{1}{16}$″) Apples and Grated Carrots, Dehydrated by Infrared Energy with the Drying Lamps 7½″ from the Trays.

Material.	Wt. in Gm.		Drying Time		Per Cent of Original Remaining.	
	Original	Dried	Hour	Minute		
Sliced apples	100	25		53	25	Final avr. of 3 samples after 24 hours = 15.2%
Sliced apples	100	29		53	29	
Sliced apples	148	40		53	27.1	
Grated carrots	200	26	1	05	13.0	
Grated carrots "blanched"	188	18	1	05	9.6	

where peeled and cut in thin ($\frac{1}{16}$″) circles while the carrots were scraped, washed, then roughly grated. Portion of the carrots were blanched (pre-cooked) for 3 minutes, drained, then dehydrated.

SUMMARY.

1. This paper deals only in a preliminary nature with infrared radiation in the dehydration of fruits and vegetables.

2. Based on the studies thus far carried out with: apples, beets, carrots, celery, potatoes and spinach, drying lamps of the type used in these preliminary investigations seem to provide a reasonably practical answer to the dehydration problem.

3. The flexibility, ease of control and amount and intensity of energy required during dehydration are three factors highly significant.

4. Infrared radiation, as applied to the dehydration of fruits and vegetables, may probably be satisfactorily applied to the dehydration of meats.

5. Radiant energy as obtainable from the drying lamps offers a vast field of application in agriculture.

Cotton Serving the Nation.—J. Lester Crain in *Manufacturers Record*, Vol. 112, No. 7, states that it is difficult for the average citizen to visualize the myriad items in which cotton is the principal raw material. A literal translation of "myriad" would not make the above statement an exaggeration, for the Army alone uses approximately 11,000 different items made of cotton. In addition to the usual articles of clothing and shelter, cotton is pinch-hitting for such unrelated critical materials as leather, aluminum and jute—to name a few of the many substances from which articles that are very scarce, yet necessary, are made. Many of these new uses of cotton products are interesting because they are unusual applications of the ordinary cotton fabrics. Others hold the interest of not only the cotton industry, but those industrial engineers engaged in the manufacture of automobiles, airplanes, ships, shoes, luggage—and home builders as well—since these new developments are the results of scientific research and possess built-in properties for specific uses. Some of the articles of clothing worn by our troops are so foreign to our old ideas of cotton as a summertime fabric that an entirely new field may be opened to cotton. The Quartermaster Corps has developed clothing for our forces in the Arctic regions which consists of soft, light layers of insulating material, covered with a wind-resistant cotton fabric. For the ski and snowshoe troops, it has designed a parka made of two water repellent, wind-resistant cotton poplins sewn together. Jungle sleeping equipment is an example of the ingenious manner in which cotton's all-round usefulness is being employed. A comfortable hammock, which can be suspended between two trees, is virtually a small room. It contains a mattress pad, a netting to keep out insects, a sling for the soldier's rifle, and a waterproof covering all made from cotton. Rapid strides have been made in the past few years in the development of finishes to render cotton fabrics resistant to fire, water, and mildew. Cotton boots, washable and rot proof against soil chemicals and micro-organisms, are furnished our jungle troops. Made of 90 per cent. cotton and having rubber soles, they out-wear three to five pairs of good G.I. shoes. All cotton supply parachutes are used to deliver food and ammunition to marooned troops, and cotton duck is the base fabric in rubberized lifeboats that are furnished plane crews.

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ON THE GEOMETRY OF COLORSPACE.*

BY

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1. INTRODUCTION.

Color has been used in articles of commerce throughout the ages but only recently has it been specified scientifically. Color names do not give a precise specification and it is necessary to use some kind of a numerical designation of color. A scientific numerical designation has been worked out and agreed on internationally. This is called the C.I.E.[1] designation and is now being used by manufacturers of textiles, papers, inks, paints, and many other things.

The international method of color specification is based on experiments with color matching. Take any arbitrary colored light and let it shine on the left part of the white screen of Fig. 1. Then illuminate the right half of the screen by means of three colored lamps, say red, green, and blue, which may be called *primaries*. It is found experimentally that the arbitrary light can always be balanced by a suitable combination of the three primaries. It is true that sometimes one or two of them must be transferred to the other side of the screen to obtain a perfect match, but *in no case are more than three primaries necessary.* This is the fundamental law of colorimetry.[2]

The three primaries need not be red, green, and blue but may be any colors, with one restriction. This restriction is that no two of the primaries can be combined to match the third.

2. THE AFFINE SPACE.

As stated previously, the fundamental law of colorimetry allows any color to be specified by three numbers. It is convenient to represent a color geometrically, and evidently a simple representation is by a point in a three-dimensional affine space (Fig. 2). Suppose the three numbers representing amounts of the three primaries are x^1, x^2, and x^3. Then the origin of coördinates represents zero light. All points P on a line through the origin represent the same color quality but different brightnesses. Thus a linear scale of brightness can be set up along any

* Presented before the Mathematics Colloquium, Massachusetts Institute of Technology, December 14, 1942.

[1] Commission Internationale de l'Eclairage, Geneva, Switzerland, 1924. See report by E. C. Crittenden, *I. E. S. Trans.*, 19, 607 (1924).

[2] *Discussion on Vision*, Cambridge Univ. Press, 1932, p. 60.

line through the origin, as in any affine space, but scales on different lines cannot be compared.

Additions of colored lights are obtained by adding the point coördinates of the component lights and are represented geometrically by the ordinary vector parallelogram.

The brightness or helios [3] of the color is represented by a linear equation

$$u_1x^1 + u_2x^2 + u_3x^3 = H. \tag{1}$$

But this is the equation of a plane in the affine space. Thus a surface of constant helios is always a plane and the various values of helios result in parallel planes.

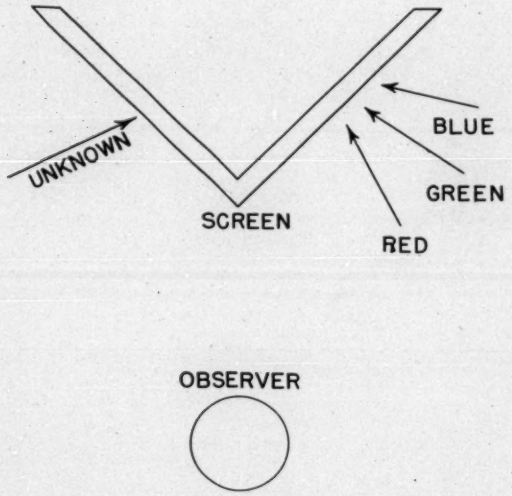

FIG. 1. Schematic diagram for the basic measurements on color matching. Observer views a two-part white screen and adjusts three controls until the two half-fields appear identical.

Transformation from one set of primaries to another is performed by the rules of affine transformation of coördinates. As pointed out previously, any three non-linear primaries can be used. Different colorimeters will have different primaries and it is necessary to change from the readings obtained with one set of primaries to readings obtained with another set of primaries. This can always be done by an affine transformation.

[3] Parry Moon, "A System of Photometric Concepts," *J. Opt. Soc. Am.*, **32**, 348 (1942).

In particular, it is convenient to have one standard set of primaries in terms of which everyone agrees to express his results. This is the C.I.E. system which is used throughout the world. Since primaries are transformed by an ordinary affine transformation, there is no reason why one cannot transform experimental results to a set of primaries which are not physically realizable. Such a set of primaries is used in the C.I.E. system. None of these primaries can be obtained by an actual light and two of them are taken with zero helios. The Y-coördinate in the C.I.E. system gives the helios directly.

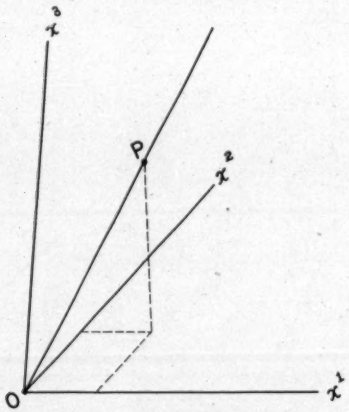

FIG. 2. The affine colorspace. A color is represented by a point P and is designated by three numbers (x^1, x^2, x^3).

3. THE METRIC

In the affine space, distances between colors cannot be compared in general and the data on color matching give no information on this subject. It is interesting to introduce a metric into the previous affine space. The first attempt of this kind was made by Helmholtz [4] but his metric did not agree with experimental results on color discrimination. In 1920 Schrödinger [5] obtained a different metric which also was in poor agreement with experiment. Silberstein [6] has also worked on the subject.

[4] H. v. Helmholtz, "Kurzeste Linien im Farbensystem," *Berlin Akad. Sci.*, 1071 (1891). *Handbuch der physiologischen Optik*, 2nd ed., Leipzig, 1896.

[5] E. Schrödinger, "Grundlinien einer Theorie der Farbenmetrik im Tagessehen," *Ann. d. Phys.*, 63, 481 (1920).

[6] L. Silberstein, "Investigations on the Intrinsic Properties of the Color Domain," *J. Opt. Soc. Am.*, 28, 63 (1938). "Fundamental Criterion of Uniform Representability of Equiluminous Colors on a Geometrical Surface," *J. Opt. Soc. Am.*, 32, 552 (1942).

The most recent experimental results on color discrimination in a plane of constant helios are those of MacAdam.[7] He made color matches by varying his color in different directions in the colorspace. The standard deviation of his results, when plotted in different directions in the colorspace is found to give an ellipse. The ellipses which he determined experimentally are shown in Fig. 3.

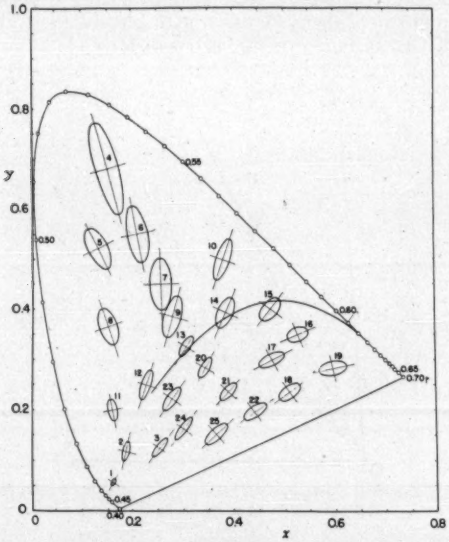

FIG. 3. The C.I.E. chromaticity diagram and the MacAdam ellipses. Each ellipse represents the standard deviation of color-matching measurements made by altering the color slightly in different directions from a fixed color point.

Consider the relation between the coördinates in terms of which this diagram is plotted and the color three space. Fig. 4 shows the ordinary C.I.E. colorspace. The two dimensional diagram shown previously is plotted in the $X-Y$ plane. The two-dimensional coördinates are obtained from the three dimensional ones in the following manner. The point is projected unto the unit plane by means of a line through the origin and is then projected unto the $X-Y$ plane by a line parallel to the Z-axis. It is obvious that if the MacAdam ellipses are replotted in a plane of constant helios both their orientations and magnitudes will change considerably.

[7] D. L. MacAdam, "Visual Sensitivities to Color Differences in Daylight," *J. Opt. Soc. Am.*, **32**, 247 (1942).

The result of plotting these ellipses in the plane of constant helios ($H = 150$ blondels) is shown in Fig. 5. The surprising result is obtained that the experimental data can be fitted by ellipses all of whose axes are parallel. This gives the possibility of introducing a Euclidean metric [8] into the plane of constant helios, provided simple analytic expressions can be found for the variation in major and minor axes. It is convenient to introduce the new variables U and V which are

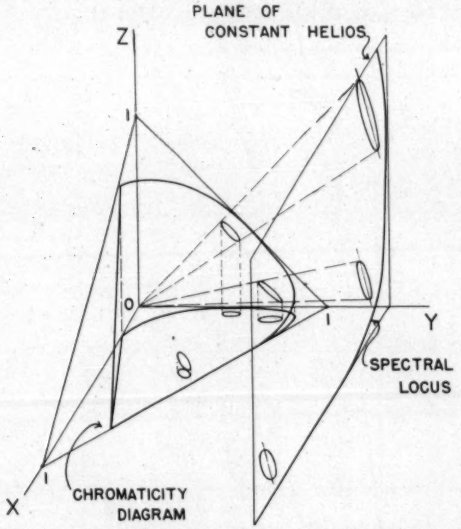

FIG. 4. The C.I.E. colorspace and its relation to the chromaticity diagram. The origin represents complete darkness, and any line from O is a line of constant color quality, or *constant chromaticity*. Such a line pierces the sloping plane (111), and the projection of the intersections onto the XY-plane gives the C.I.E. chromaticity diagram. The intersection of lines of constant chromaticity with a vertical plane (Y = const.) gives another useful diagram.

measured along the axes:

$$U = 0.974X - 0.226Z, \qquad V = 0.226X + 0.974Z. \tag{2}$$

In Fig. 6 the plot of the semi-major axes versus V is shown. The points can be fitted by the expression

$$\frac{2.20 + 0.540(V/100)^2}{1 + 0.180(V/100)}. \tag{3}$$

[8] Parry Moon and D. E. Spencer, "A Metric for Colorspace," *J. Opt. Soc. Am.*, 33, 260 (1943).

Fig. 7 shows the semi-minor axes plotted versus U. And the points can again be fitted by an expression of the second degree:

$$0.60 + 0.268(U/100 - 1)^2. \tag{4}$$

These expressions determine the metric in the plane of constant helios. Since U and V may be taken orthogonal, the coefficient g_{13} is zero.

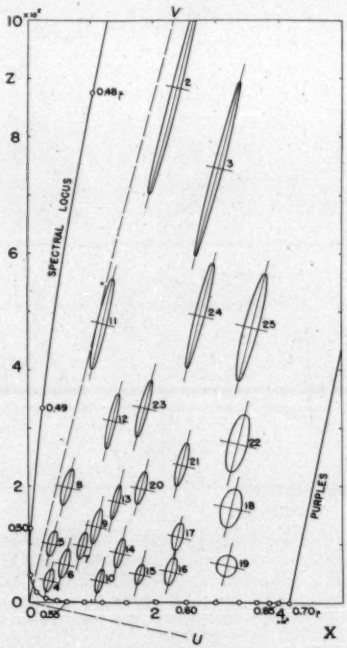

FIG. 5. The MacAdam ellipses transformed to a plane of constant helios (Y = const.). These ellipses represent the same data as those of Fig. 3.

The metric in this plane is therefore written

$$ds^2 = \frac{dU^2}{[0.60 + 0.268(V/100 - 1)^2]^2} + \left[\frac{1 + 0.180(V/100)}{2.20 + 0.540(V/100)^2}\right]^2 dV^2. \tag{5}$$

The constants have been chosen in such a way that the standard deviation $\Delta s = 1$.

This is evidently a Euclidean metric, for it can be written

$$(6) \quad ds^2 = (d\xi^1)^2 + (d\xi^3)^2,$$

if $\xi^1 = 250 \tan^{-1}(0.668(U/100 - 1))$,
$\xi^3 = 91.8 \tan^{-1}(0.495V/100) + 16.67 \ln [2.2 + 0.54(V/100)^2]$.

By the use of additional data the metric in the color three space can be determined. Stiles and Crawford [9] have measured the minimum perceptible variation in helios along any line of constant quality. In

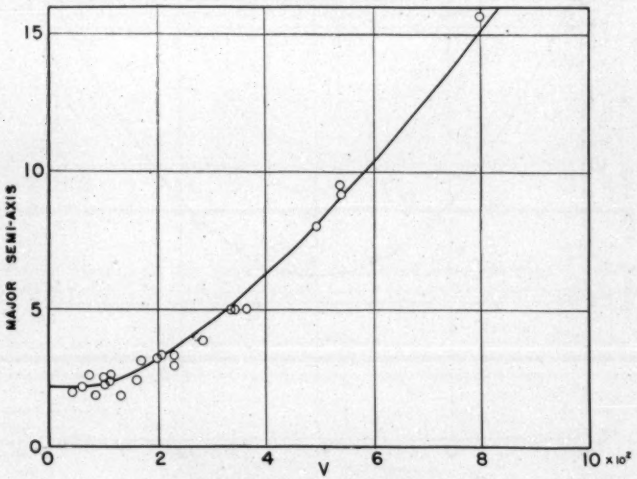

FIG. 6. Semi-axes of the ellipses of Fig. 5.

the range of values for which the C.I.E. specification has meaning

$$(7) \quad (\Delta Y)_{\min} = .005Y.$$

Taking a variation along a line of constant quality, we obtain

$$(8) \quad \frac{dU}{U} = \frac{dV}{V} = \frac{dY}{Y},$$

which gives

$$(9) \quad ds^2 = \left(\frac{dY}{Y}\right)^2 [g_{11}U^2 + g_{22}Y^2 + g_{33}V^2] = \left(\frac{dY}{.005Y}\right)^2.$$

[9] Stiles and Crawford, "The Liminal Brightness Increment for White Light for Different Conditions of the Foveal and Parafoveal Retina," *Roy. Soc., London, Proc.*, **116B**, 55 (1934), "The Liminal Brightness Increment as a Function of Wavelength," *Roy. Soc., London, Proc.*, **113B**, 496 (1933).

This is if the axes are assumed orthogonal. Therefore the third metric coefficient is

$$g_{22} = \frac{1}{Y^2}[(200)^2 - g_{11}U^2 - g_{33}V^2]. \tag{10}$$

Consequently, in the ξ-space any pair of just perceptible colors are separated by the same distance and the minimum perceptible surface about any point is a sphere. The MacAdam ellipses are fitted by

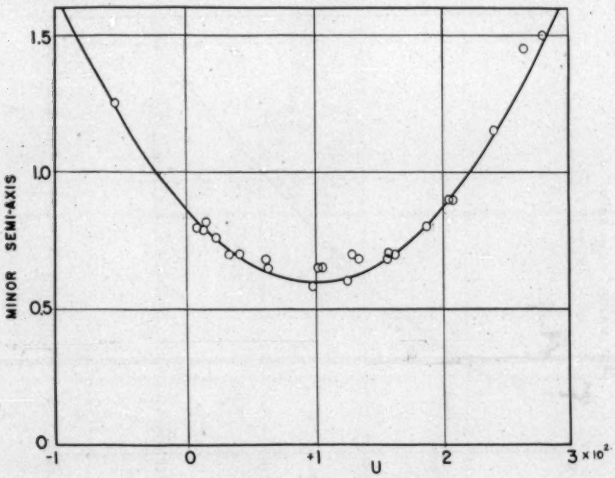

FIG. 7. Semi-axes of the ellipses of Fig. 5.

circles as shown in Fig. 8. In the ξ-space Fig. 9 shows a plot of the MacAdam ellipses and the spectral locus. Geodesics are of course straight lines.

4. ADAPTATION.

The previous work has neglected the effect of the surround. But it is generally recognized that the surround has a very definite effect on the appearance of a color. For example, a bright orange light with a dark surround appears brown when a bright white surround is used. Thus it becomes advisable to consider the state of adaptation of the eye and to try to bring this into the color specification scheme. A small color patch can be represented by three numbers and the state of adaptation of the eye is represented by three numbers. Thus the whole thing can be represented by six numbers. But it is advisable to decrease the number of variables.

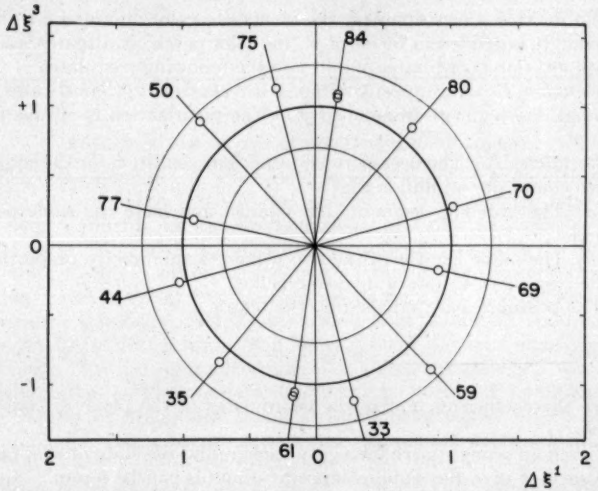

FIG. 8. MacAdam's data for a typical ellipse, transformed into ξ-space. Within the limits of experimental error, the points appear to be represented in a satisfactory manner by a circle.

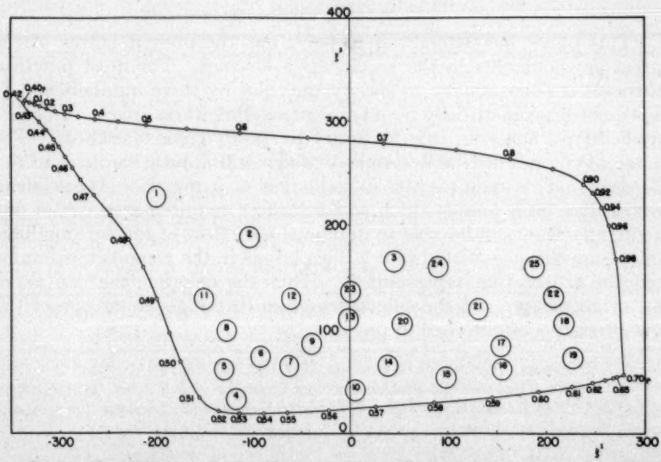

FIG. 9. The ξ-diagram, obtained by means of a non-linear transformation of the diagram of Fig. 5. The MacAdam ellipses now become circles, all of unit radius. In this way the color-discriminating ability of the eye is given a simple geometric representation; for unit distance in any direction and at any point is here a measure of the minimum perceptible color difference.

To do this a new concept, the composite color stimulus,[10] is introduced. It is defined in terms of y^k, the color patch coördinates, and x^k, the adaptation coördinates, subject to the following postulates:

Postulate I. A composite stimulus is represented geometrically by a directed line segment from x^k to y^k. The polarization is always from x^k to y^k.

Postulate II. The necessary and sufficient condition for the equality of two composite stimuli is that

(*a*) The two line segments are parallel and have the same polarization;

(*b*) The affine lengths of the two segments are directly proportional to the respective values of adapting helios.

The postulates are satisfied by the tensor

$$p^i = \frac{y^i - x^i}{u_k x^k}, \qquad i, k = 1, 2, 3, \tag{11}$$

where the coefficients u_k are the coördinates of the plane of constant helios.

Given an orange patch on a gray background the state of adaptation necessary to give the same composite stimulus can be found. And it results that the background must be blue to make the gray patch look orange. Such facts are in accordance with experiments.[11]

5. CONCLUSIONS.

This paper has attempted to point out the present status of the latest developments in the specification of color. For most practical purposes it is customary to specify the color by three numbers and to represent it geometrically by a point in an affine three space. In other applications, however, it is necessary to specify color tolerances. The range of colors must be determined which will appear identical to the observer. This requires the introduction of a metric. A Euclidean metric has been found which satisfies these requirements. Also one frequently wants to be able to designate the effect of the surroundings on the appearance of the color. This brings in the composite stimulus and the tensor that represents it. Thus the colorimetrist can make use of geometry, and the colorspace gives to the geometer one of the few affine spaces obtained in physics.

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[10] D. E. Spencer, "Adaptation in Colorspace," *J. Opt. Soc. Am.*, 33, 10 (1943).

[11] H. Helson, "Fundamental Problems in Color Vision," *J. Exp. Psychol.*, 23, 439 (1938). D. B. Judd, "Hue Saturation and Lightness of Surface Colors With Chromatic Illumination," *J. Opt. Soc. Am.*, 30, 2 (1940).

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

SPECIFICATION OF THE MUNSELL BOOK OF COLOR.

The development of the Inter-Society Color Council-National Bureau of Standards (ISCC-NBS) system of color names, based on the color standards in the Munsell Book of Color (*Technical News Bulletin 269* (September, 1939)), made it necessary to specify the master standards of this book in basic terms. Accordingly, the spectral reflection curves of the 421 Munsell Standards were run, and the resulting colorimetric specifications were obtained for four illuminants, equivalent respectively to incandescent-lamp light, average daylight, lightly overcast north sky, and extremely blue sky. Average daylight was previously chosen as the standard illuminant for use in determining the color names of drugs and chemicals, and colorimetric charts have, therefore, now been prepared with this illuminant from which it is possible to select the appropriate color name descriptive of a color, if its colorimetric specifications are given. Thus, the ISCC-NBS system of color names has, by this present fundamental or basic specification of the Munsell Standards, been made independent of the existence of the Munsell or any material color standards and can be determined, if desired, through the use of an appropriate spectrophotometer or colorimeter. This accomplishment is discussed in detail in a paper (RP1549) by Kenneth L. Kelly, Kasson S. Gibson, and Dorothy Nickerson in the August number of the *Journal of Research*.

OPTICAL ROTATION AND ATOMIC DIMENSIONS.

In continuing an investigation of optical rotation and atomic dimension, Dirk H. Brauns, formerly a member of the Bureau's polarimetry section, has extended his studies to specially prepared halogen derivatives of optically active pentanol-2. In the writer's previous investigations he suggested that certain optically active halogen derivatives may be divided into two classes. The first class has the halogen directly attached to an asymmetric carbon atom. For these substances the writer has formulated the rule that the differences of their *specific* rotations (Cl-F), (Br-Cl) and (I-Br) have the same numerical relation as the respective differences of the radii of the covalent-bonded halogen atoms (41 : 17 : 21). The second class of optically active halogen derivatives has the halogen attached indirectly (by a chain of atoms) to an asymmetric carbon atom. For these latter substances the rule

* Communicated by the Director.

was formulated that the differences of their *molecular* rotations have a numerical relation, which likewise agrees with that for the respective differences of the radii of covalent-bonded halogen atoms.

As these rules were established for halogen derivatives of carbohydrates, which contain several asymmetric carbon atoms, it was found desirable to investigate halogen derivatives, which contain only one asymmetric carbon. The halogen derivatives of two active amyl alcohols were chosen for this investigation, and the results of the last communication (*J. Research NBS*, **18**, 315 (1937); RP978) showed that the derivatives of the amyl alcohol, 2-methylbutanol-1, checked the above rule for class II very well. The present communication (RP1551 in the August *Journal of Research*) reports the results obtained in checking the above rule for class I with the halogen derivatives of the other active amyl alcohol, pentanol-2. Pure optically active D- and L-pentanol-2 were prepared and halogenated by different methods for obtaining the highest-rotating 2-fluoro-, 2-chloro-, 2-bromo- and 2-iodopentane.

In spite of the difficulty that a partial inversion takes place in the halogenation, resulting in a mixture of D and L halogen derivative, the conclusion can be drawn that rule I is not contradicted by the values found, since the deviations can be plausibly explained by the incompleteness of the Walden inversion. Rule II should not be applicable to this type of compound and the results confirm this premise.

It is further shown that all halogen derivatives of pentanol-2 of like configuration have the same sign of optical rotation. The specific gravity, refractive index, and boiling points at various pressures, were also determined.

THEORY OF THE POTENTIAL AND THE TECHNICAL PRACTICE OF ELECTRODEPOSITION.

A paper by Charles Kasper which will appear in the *Transactions of the Electro-chemical Society* deals with the effect of the terminal on the current distribution over an electrode in an electrolytic solution. Oddly enough, in the literature of electrochemistry no paper has dealt with this subject, in spite of the apparent wide appeal of such a publication. The present paper aims to fill the need and to make available to electrochemists an outline of the knowledge of mathematical physics through which it is possible to obtain definite ideas concerning the terminal effect.

Only one other paper in any literature deals with the terminal effect of an electrode in an electrolytic system; this is by Chester Snow and was published in *J. Research NBS*, **17**, 101 (July, 1936), RP905. In the present paper the subject is extended to other possible mathematical models that may be of practical importance in modern electroplating engineering. It is particularly in the recently developed continuous

processes of electroplating of strip steel and round wire that dimensions (of the electrode) are encountered where the effect no longer may be of secondary importance or insignificant. It definitely must be taken into consideration in the "acid tin plating" of sheet steel for which so many installations are being erected at the present time. With these large scale installations there is the element of geometrical simplicity in the plating arrangement which is ideal for the application of mathematical methods, and the results obtained should be of value to the plant designers.

BRAZILIAN RUBBER LABORATORY.

The Bureau is assisting the Brazilian Government in the installation of a modern rubber laboratory at the Instituto Agrinomico do Norte at Belem (*Technical News Bulletin 308;* December, 1942).

Word has been received that nearly all the machinery, supplies, and equipment purchased for the laboratory in the United States, have now arrived safely and are in process of installation. Even in advance of the completion of the laboratory, Norman Bekkedahl of the Bureau's rubber section, who is in charge of the work, and his assistant, Fred L. Downs, have been able to start investigations on methods of tapping and the preparation of crude rubber.

The location of the new laboratory at the mouth of the Amazon River gives it convenient access to a wide variety of rubber-producing trees and plants; moreover, this strategic location should make it possible for the laboratory staff to aid in developing the entire Brazilian rubber industry. This is the only rubber laboratory in the tropics serving the United Nations.

THERMAL EXPANSION OF COPPER ALLOYS.

A paper (RP1550) by Peter Hidnert and George Dickson in the August number of the *Journal of Research* gives data on the linear thermal expansion of some industrial copper-nickel, copper-nickel-aluminum, copper-nickel-tin, and miscellaneous copper alloys (copper-tin, copper-lead-antimony, copper-manganese-aluminum, copper-nickel-iron, copper-nickel-zinc, copper-nickel-tin-lead, copper-nickel-zinc-iron, copper-tin-zinc-lead, copper-zinc-iron-manganese) for various temperature ranges between 20° and 900° C. The addition of 3 per cent. nickel or the combined addition of 4.5 per cent. nickel and 5 per cent. aluminum to copper was found to have little effect on the linear thermal expansion. The effect of various treatments on these copper-nickel and copper-nickel-aluminum alloys was also small.

The coefficients of expansion of two copper-nickel-tin alloys containing 20 and 29 per cent. nickel were appreciably less than the coefficients of expansion of copper for temperature ranges between 20° and

600° C. For the range from 20° to 900° C. the coefficient of expansion of the copper-nickel-tin alloy containing 20 per cent. nickel is about 16 per cent. higher than the coefficient of expansion of copper.

Three copper alloys containing more than 28 per cent. nickel showed the smallest coefficients of expansion of the miscellaneous alloys.

The coefficients of expansion of the copper alloys reported in this paper were found to be between 14.9×10^{-6} and 20.4×10^{-6} per degree C. for the range from 20° to 100° C.

AIR PERMEABILITY FINENESS APPARATUS.

A new apparatus has been designed by R. L. Blaine of the Bureau's cement section for measuring the fineness of granular materials by the air permeability method. The new apparatus is analogous to the "U" tube viscometer in which the liquid in the tube provides the pressure difference and also serves to indicate the volume of flow. For comparative and control purposes, the fineness can be expressed in terms of the time required for a definite volume of air to pass through the sample. The apparatus is inexpensive, simple both to make and to operate, and necessitates practically no critical materials. The method of testing is rapid, less than 10 minutes being required for a complete determination. Although designed primarily for comparative tests, the specific surface values can be calculated from the constants of the instrument.

The results of tests with portland cements indicate that the fineness values obtained are reproducible and are in agreement with values obtained with the Lea-Nurse type air-permeability apparatus.

PROPERTIES OF CONCRETES MADE WITH VARIOUS TYPES OF CEMENTS.

A knowledge of the tensile strength of concrete is important in studying failures of this material as the result of shrinkage, temperature variation, or other factors which may cause disruption. An improved tensile test method, developed at the Bureau by Louis Schuman and John Tucker, Jr., employs cylindrical specimens, 4 × 16 inches. Loads are applied through threaded rods embedded in a rich mortar at the ends of the specimens.

Compressive and tensile strengths have been determined for concretes made with a number of cements of various types, including 5 normal, 4 moderate-heat, and 3 high-early-strength portland cements; 2 portland-pozzolan; 1 high alumina cement; and 9 cements containing aerating agents. This last type has been used to reduce the disruptive effects of freezing and thawing. Stress-strain determinations in both tension and compression have also been made on the aerated concretes and on one normal concrete. The effects of varying sand-gravel ratio and of various coarse aggregates on tensile strengths were also studied.

According to the report on this work in the August *Journal of Research* (RP1552), cements of the moderate-heat type, often used in large structures to prevent undue temperature rise, gave but slightly lower compressive and tensile strengths at early ages than normal portland cements. At later ages the strengths of these cements, both in tension and compression, often exceeded other types. The high-early-strength cements gave appreciably higher strengths at early ages than the other types of cement. The use of either a high-early-strength cement, or of a richer mix with a normal cement, appears to have greater advantage in securing high early tensile strength than high early compressive strength.

Aerated concretes were relatively high in tensile strength up to 7 days; thereafter both compressive and tensile strengths, as well as moduli of elasticity, were lower than for normal cements.

With some cements, tensile strengths attained maximum values between 7 days and 3 months. Tensile strengths were related to compressive strengths. For the same cement, tensile strengths varied greatly with sand-gravel ratio and the type of coarse aggregate used in the concrete.

PROPERTIES OF PORTLAND POZZOLANA CEMENTS.

The use of domestic portland pozzolana cements has increased markedly during the past decade. Because of a scarcity of data, an investigation of some properties of these cements was started about 9 years ago by G. L. Kalousek and C. H. Jumper. As explained in an article on this work that will be published in the *Journal of the American Concrete Institute*, a group of 10 commercial portland pozzolana cements, 2 Santorin Earth blends, together with 2 standard portland and 1 natural cements, were used. The cements were tested for all or some of the following properties: Tensile and compressive strengths; resistances to cycles of freezing and thawing, and of freezing, thawing and drying (at 65° C.); linear changes caused by periodic alternations of the specimens between damp closet and laboratory; resistances to solutions of sodium and magnesium sulfates; linear changes during autoclaving; and heats of hydration. Chemical analyses were also made.

The strengths of the commercial portland pozzolana cements for the most part approximated and in some instances exceeded those required by specifications for portland cements. The 2 laboratory blends and the natural cements gave low strengths. The linear changes of the concrete specimens, stored alternately in the damp closet and the laboratory, were nearly the same for all cements with the exception of one portland pozzolana cement which showed a small but continuous growth. The portland pozzolana cements showed a better resistance to cycles of freezing, thawing, and drying (at 65°) than did the portland cements. However, no definite trends were manifested in the freezing

and thawing tests. The commercial portland pozzolana cements showed better resistance to the action of a 10 per cent. solution of Na_2SO_4 than the portland cements at 4 weeks. For longer exposures, however, the greater number of both types of cements had poor resistance.

The linear changes of neat bars caused by autoclaving were small for 4 of the 5 portland pozzolana cements tested; the fifth showed an intermediate expansion. The heats of hydration determined for 5 portland pozzolana cements ranged from 52 to 79 cal./g. (average of 62) at 7 days from 70 to 96 cal./g. (average of 79 at 28 days).

PHYSICAL PROPERTIES OF TERRAZZO AGGREGATES.

A study of the physical characteristics of 77 marbles used for terrazzo aggregates was recently completed at the Bureau in order to supply data for a specification control on the quality of terrazzo chips. The samples were supplied by 24 producers from quarries operated in 12 states, and were classified as calcites, dolomites, dolomitic marbles, serpentines, and travertines. Abrasive resistance, bulk specific gravity, absorption, and toughness tests were made on the rock in its natural state, while percentages of dust and voids, and thickness grading tests were made on samples of No. 2 aggregate (chips passing a 3/8 and retained on 1/4 mesh). A few samples, including two which were reported to have given trouble in terrazzo installations, were subjected to further tests to determine their expansion while absorbing water, and contraction while drying. One sample was tested for thermal expansion over the range $-24°$ to $+60°$ C.

Only a few samples were found to be of low wear resistance, and over half should be satisfactory for heavy traffic conditions. Absorption values varied over a wide range, the lowest being 0.03 per cent. for a black marble, and the highest 7.4 per cent. for a weathered serpentine. This test indicates the relative susceptibility of various aggregates to absorb staining matter. Bulk specific gravity values varied from 2.20 for a weathered serpentine to 2.98 for a dolomite, corresponding to weights of 137 to 186 lb./ft.^{3} for the rock in its natural state. Several samples gave toughness values (resistance to impact) below 5. Samples of low toughness included the travertines and coarsely crystalline materials. This property is a measure of tenacity, and aggregates of low toughness show a tendency to form appreciable amounts of dust in the shipping containers.

The spaces between chips (voids) have a bearing on the actual volume of stone in portions measured for mixing. The percentage of voids is affected by the shape of particles as well as by their grading from fine to coarse. Aggregates in which the shape of particles is nearly equidimensional have voids as low as 40 per cent., while aggregates containing many flat or elongated chips have voids over 50 per cent.

When portions of aggregate are weighed to obtain the mix proportions (usually 1 part cement to 2 parts aggregate), the corresponding volumes may vary considerably. A given weight of a light aggregate having high voids may differ in volume from that of the same weight of a heavy aggregate having low voids by as much as 30 per cent. The percentage of voids in a well compacted aggregate is from 3 to 5 per cent. less than when portions are measured without compacting.

A test was devised to separate samples of No. 2 aggregate into four fractions with respect to particle thickness. The results show characteristic differences between aggregates that are not indicated by other tests. One aggregate reported to give frequent trouble in terrazzo floors was found to have over 80 per cent. of particles less than 3/16 in. thick. Terrazzo mixtures are usually made with an excess of cement paste and rolled, after placing, to remove the surplus. It seems likely that the shape of chips may have a pronounced effect on the amount of paste that can be removed by rolling.

One sample expanded considerably during the absorption of water and contracted a similar amount in drying. The change was approximately equal to that accompanying a 70° C. change in temperature. The thermal expansion of an impure calcite was found to vary greatly over different temperature intervals and also for different directions in the stone. The highest coefficient was 0.0000087, but negative coefficients were found for one direction of measurement between 10° and 25° C.

The complete account of this work will be found in Building Materials and Structures Report BMS98, copies of which are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 15 cents each.

WALL CONSTRUCTION WITH FIBER INSULATING BOARD.

Fiber insulating board has been widely used for interior finish in dry-wall construction. However, certain properties of the material have heretofore restricted the choice of surface design and decoration to paneled effects and painted finishes. In a recent investigation at the Bureau the difficulties which have prevented the use of other methods of design and decoration were traced to the conventional means adopted for fastening the boards to the framing.

As explained in *Building Materials and Structures Report BMS97*, which was released a short time ago, it was found possible to overcome these difficulties by eliminating the usual nailing and substituting invisible flexible fasteners. This principle of fastening the boards in place permits the entire surface of a wall or ceiling to expand and contract as a single unit with variations of relative humidity. Several methods of fastening to obtain these "floating" effects were worked

out and used successfully in experimental walls. Their use permitted the application of all of the decorative treatments normally applied to plaster walls, including papering. Paneled effects were not required.

Copies of BMS97 are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C. The price is 10 cents.

STRUCTURAL AND HEAT-TRANSFER PROPERTIES OF "MULTIPLE BOX-GIRDER PLYWOOD PANELS."

To determine structural and heat-transfer properties, tests were conducted by the Bureau in coöperation with the Forest Service, U. S. Department of Agriculture, at the request of the War Department on wall, floor, and roof specimens of "Multiple Box-Girder Plywood Panels" sponsored by Loren H. Wittner. The specimens were constructed by gluing and nailing one sheet of plywood between two frames and facing the outer surfaces with other sheets of plywood. The longitudinal and transverse members of the frames with the sheets of plywood formed closed cells, which provided heat insulation.

The wall specimens were subjected to compressive, transverse, concentrated, impact, and racking loads; the floor specimens to transverse, concentrated, and impact loads; and the roof specimens to transverse and concentrated loads. The loads simulated those to which the elements are subjected in actual service.

The deformations under load and the sets after the load was removed were measured for uniform increments of load. The results are presented in graphs and tables.

The heat-transfer properties of three wall specimens were determined in a shielded hot-box heat-transfer apparatus.

The results of these tests have just been published as *Building Materials and Structures Report BMS99*. Copies are obtainable at 15 cents each from the Superintendent of Documents, Government Printing Office, Washington, D. C.

RELATIVE SLIPPERINESS OF FLOOR AND DECK SURFACES.

The slipperiness of any surface is important to the physical well-being of those who walk on it. Considerable thought has been given to ways of improving the antislip characteristics of paving and flooring materials. Probably the most common method is to provide a roughened surface. This is accomplished by corrugating or embossing some floor coverings and in other cases by embedding rough abrasives in the surface. Rough surfaces are difficult to maintain and keep clean and thus are not desirable for general indoor use. On the other hand, smooth-faced materials are extensively employed as floor coverings, and information on their relative slipperiness is important.

With this need in mind, a machine has been constructed by Percy A. Sigler at the Bureau which incorporates a new and practical method of determining the relative slipperiness of floor surfaces under both dry and wet conditions.

The machine and method of testing are described in *Building Materials and Structures Report BMS100*, which was released a short time ago. The results of tests of 116 floor and deck materials are given, including such general types as stone, terrazzo, cement-mortar, magnesite, ceramic tile, metal, asphalt, rubber, linoleum, and wood.

Test data are given, showing the effect of abrasives, embossments, and different wax finishes on the antislip properties of selected floor materials.

In general, considerable difference in slipperiness was found between dry and wet surfaces. Most of the floor materials showed satisfactory antislip properties when dry, whereas many would be classed as hazardous when wet.

Copies of BMS100 are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents each.

Developments in Riveting.—(*Army Ordnance*, Vol. XXV, No. 139.) Radio frequency energy now is used to detonate explosive rivets and speed production of aircraft. The radio unit assures instant control of temperature in the firing tip, eliminating time consumed in heating an electric iron to operating degrees and in frequent changes from one tip temperature to another. This method is adaptable only to large-scale production. The electric riveting iron, now used widely, is still preferred for many types of work. Explosive rivets were introduced two years ago, breaking a bad bottleneck in fastening airplane sections where riveters could work from only one side. They are installed at a rate of fifteen to twenty a minute, as contrasted with two to four a minute for most "blind" fasteners. The rivet has a high explosive secreted in a cavity at the end of the shank. Heat applied to the rivet head detonates the charge. The explosion expands the charged end of the shank, forming a "blind" head and setting the rivet. Engineers of Radio Corporation of America and of the Du Pont Company developed the radio unit, which consists of an oscillator together with a specially prepared applicator to concentrate current directly into the rivet head. As current is induced in the head, the heat it creates fires the charge. Radio energy not only gives instant temperature control but prolongs indefinitely the life of the firing tip. The tip is always cool, an important safety factor. The same tip can be used for any kind of rivet head. Another development is an automatic rivet injector designed to obviate lost motion and the loss of rivets resulting from conventional riveting practice in the aircraft industry recently announced by the manufacturing research department of Vultee Aircraft, Inc. Seen as an aid to speeding up production, the device is a portable riveting tool with an automatic injector which inserts the rivet in the hole and performs the riveting operation without the necessity of removing the tool from the work. By combining the unit with another device developed by the Vultee Field Division, known as the "riveting yoke," complete riveting operations can be carried on by one person. This combination also makes it possible to provide a hopper-type feed containing large quantities of rivets. The automatic rivet injector is designed to fit any standard riveting gun. The unit is compact and adds very little weight to the gun.

R. H. O.

THE FRANKLIN INSTITUTE

JOSEPH SWEETMAN AMES

1864–1943.

We deeply regret to announce the death of Joseph S. Ames, who was Associate Editor of the JOURNAL OF THE FRANKLIN INSTITUTE from 1921 to 1943. He served The Franklin Institute well not only in the above capacity, but also as a member of the Bartol Research Foundation Committee (1922–27) and of the Committee on Meetings (1922–24). He gave three lectures at the Institute, one on Einstein's Principle of Relativity and two on Aeronautical Research. He contributed six valuable papers to our JOURNAL.

Dr. Ames was born in 1864 in Manchester, Vermont. He was graduated from Johns Hopkins University in 1886 and remained there all his lifetime as a teacher and an executive officer, retiring in 1935 as President Emeritus.

He was outstanding as a teacher of physics, both in the undergraduate and graduate schools. His lectures were always well prepared and presented in a very logical and thorough manner. He made his students work, and it can be said without reservation that any student who passed his courses never had to repeat them when he moved on to other colleges for engineering or higher degrees. His textbook, "Theory of Physics," was used in the junior classes of many colleges during the early years of this century.

For twenty-four years, Dr. Ames served on the National Advisory Committee for Aeronautics, and the improvement of the performance and efficiency of American aircraft was largely due to his executive ability and farsighted policies. In recognition of his contributions to aeronautical research, the laboratory at Moffett Field, California, was named the "Ames Aeronautical Laboratory."

On account of his contributions to American Science many academic and public honors came to Dr. Ames in spite of his unassuming and modest ways. He was an inspiring teacher and a leader of men, beloved by his colleagues and students.

J. B.

LIBRARY NOTES.

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat prints of any material in the collections can be supplied on request. The average cost for a print 9 × 14 inches is thirty-five cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays from two until ten o'clock P.M.

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NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

The Preparation of Some N-Substituted 3-Pyridinesulfonamides.—FRANCIS E. REINHART. The discovery by Woods (*The British Journal of Experimental Pathology*, **21**: 74, 1940) that the bacteriostatic action of sulfanilamide is nullified by para aminobenzoic acid, as well as a wealth of evidence presented subsequently by others, has led to wide acceptance of the theory that bacteria which are sensitive to the sulfa drugs depend upon para aminobenzoic acid for normal growth and that the drugs, because of their close chemical relationship to this vital substance, exert their inhibitory action by interfering with bacterial mechanisms involved in its utilization. That this principle of antagonism between a vitamin and its sulfur analog may be rather general is indicated by the work of McIlwain. He found that pantoyltaurine (*The British Journal of Experimental Pathology*, **23**: 95, 1942), the sulfur analog of pantothenic acid, inhibited the growth of organisms which require this vitamin for growth and that 3-pyridinesulfonic acid and its amide (*The British Journal of Experimental Pathology*, **21**: 136, 1940), sulfur analogs, respectively, of nicotinic acid and nicotinic acid amide, exerted bacteriostatic action on staphylococcus and proteus, organisms known to be dependent upon these vitamins. Of particular significance was the fact that the activity of each sulfur analog was specifically lost in the presence of an excess of its respective vitamin (*Science*, **95**: 509, 1942) and remained unaffected in the presence of unrelated vitamins.

On the basis of this common principle which appears to be concerned with the bacteriostatic action of sulfur compounds of diverse chemical structure, an attempt has been made by McIlwain (*Nature*, **146**: 653, 1940) to enhance the activity of 3-pyridinesulfonamide by preparing its N-2-pyridyl derivative, since a similar substitution in the case of sulfanilamide leads to a derivative (sulfapyridine) with increased bacteriostatic potency. The new derivative, however, was found to possess less activity than the parent amide. This fact points to a lack of correlation between the activities of analogous compounds of the sulfanilamide and pyridine types, but it is possible that correlation does exist and is obscured by unknown factors, such as the degree of permeability of bacterial cell walls.

The preparation of similar N-substituted 3-pyridinesulfonamides is being studied in this Laboratory with a view to obtaining compounds possessing greater bacteriostatic activity than the simple amide. The method of preparation described by Machek (*Monatshefte für Chemie und verwandte Teile anderer Wissenschaften*, **72**: 77, 1938) and used by

McIlwain has been modified extensively, especially with respect to the preparation and purification of the intermediates required.

Since the starting material, 3-pyridinesulfonic acid, was required in considerable amounts, the method of Machek, which involves removal of excess sulfuric acid from the sulfonation mixture as barium sulfate followed by several evaporations, was found to be inconvenient. A search for an alternate procedure showed that the sulfonic acid forms a relatively insoluble mercuric salt which can be used conveniently for the preparation of the acid in a pure state.

In the second step of the synthesis Machek treated the sulfonic acid with phosphorus pentachloride (one equivalent) in order to obtain the desired 3-pyridinesulfonyl chloride. Because of its instability, attempts to isolate this compound were unsuccessful and it became necessary to use the crude reaction product for the final step in the synthesis. The present study has shown that the use of two moles of phosphorus pentachloride instead of one appears to favor stability of the compound which may be isolated in excellent yield and pure form as a hydrochloride. This salt, which is analogous to that formed by nicotinyl chloride (Späth, E., and Spitzer, H., *Berichte der deutschen chemischen Gesellschaft*, **59**: 1477, 1926), hydrolyzes instantly in water to give an oil which is undoubtedly 3-pyridinesulfonyl chloride. The latter then slowly hydrolyzes to the sulfonic acid. It is therefore necessary to preserve the salt in a moisture-free atmosphere. When treated in ether with an excess of 2-aminopyridine, it gave a compound which crystallized from alcohol in colorless prisms melting at 187° C. (uncor.). N-2-pyridyl-3-pyridinesulfonamide, as reported by McIlwain (*Nature*, **146**: 653, 1940), melts at 185° C.

This salt has been treated with amino compounds to yield several new N-substituted 3-pyridinesulfonamides. Thus, reaction with excess aniline in the absence of solvent has given a good yield of the corresponding anilide; the preparation of this compound was unsuccessfully attempted by Machek using the crude acid chloride. Reaction with ethyl p-aminobenzoate in ether has given an amide which on acid hydrolysis yields 4′-carboxy-3-pyridinesulfonanilide, while the use of 3-aminopyridine results in the formation of N-3-pyridyl-3-pyridinesulfonamide. All these amides are rather insoluble in water but, as would be expected, dissolve in dilute acids and alkalies.

Further synthetic work along these lines is in progress at the present time. The results of this work as well as of tests relating to the effects of these compounds on bacterial growth will be reported at a future date.

EXPERIMENTAL.

3-Pyridinesulfonic Acid.—Freshly-distilled pyridine (20 cc.) was sulfonated as described by Machek (*Monatshefte für Chemie und verwandte Teile anderer Wissenschaften*, **72**: 77, 1938) using fuming sulfuric acid

(60 cc.) at 230° C. for 12 hours. As a catalyst, however, one gram of the mercuric salt of 3-pyridinesulfonic acid was used instead of basic mercuric sulfate. After cooling the sulfonation mixture it was poured into ice-water (600 cc.) to which then was added a cold solution of NaOH (50 g.) in water (200 cc.). This partial neutralization resulted in a solution approximately normal with respect to acid. After clarification with Norite, $HgSO_4$ solution (130 cc., made by mixing 200 g. $HgSO_4$, 50 cc. 10 N sulfuric acid, 40 cc. conc. sulfuric acid in the order given and diluting to 700 cc. with water) was added with stirring. The cream-colored precipitate was filtered off after 12 hours, washed with normal sulfuric acid (20 cc.), then with alcohol and finally with ether. After drying at 110° C. the yield was 30.2 g.

The salt was soluble in strong sulfuric acid solutions and in aqueous solutions which contained chloride ion.

Analysis.—Calcd. for $C_{10}H_8O_6N_2S_2Hg$: Hg, 38.8. Found: Hg, 38.6.

The mercuric salt was suspended in water (300 cc.) and the mixture saturated with hydrogen sulfide. After centrifuging off the HgS, the latter was suspended in water (100 cc.) which was again treated with hydrogen sulfide and then centrifuged. Evaporation of the combined supernatant portions gave crystals of 3-pyridinesulfonic acid. After drying at 110° C. the weight was 17.3 g. (43 per cent.).

3-Pyridinesulfonyl Chloride Hydrochloride.—3-Pyridinesulfonic acid (8 g.) was mixed thoroughly with phosphorus pentachloride (21 g.) in a flask provided with an air condenser and calcium chloride tube. The flask was immersed in an oil bath which was slowly heated to 120° C. and maintained at that temperature for 90 minutes. The liquid reaction mixture solidified on cooling. In order to remove phosphorus pentachloride and phosphorus oxychloride, chloroform (75 cc.) was added and the solid material triturated before and after the introduction of excess dry hydrogen chloride. The supernatant liquid was then decanted and discarded. This process was repeated with a second 75 cc. portion of chloroform, and finally the product was triturated in a mortar with chloroform saturated with hydrogen chloride. After separation by filtration and washing with pure chloroform, the white powder was dried *in vacuo*. The yield was 9.2 g. (86 per cent.).

The compound melted with decomposition at 141–144° C. (uncor.), some sublimation occurring during the M.P. determination. It was somewhat soluble in ethanol, but insoluble in other ordinary organic solvents. It reacted instantly with water to give a water-immiscible oil which slowly dissolved with the formation of 3-pyridinesulfonic acid. The latter was precipitated as its mercuric salt after all HCl had been removed by evaporation. When dissolved in an excess of standard alkali and back-titrated with standard acid to a phenolphthalein endpoint, the apparent neutralization equivalent was found to be 71.6.

Calculated value (based on complete hydrolysis to the sulfonic acid), 71.4.

Analysis.—Calcd. for $C_5H_5O_2NSCl_2$: Cl, 33.1. Found: Cl, 33.2.

3-Pyridinesulfonanilide.—3-Pyridinesulfonyl chloride hydrochloride (3.2 g.) was added to aniline (17 cc.) and the mixture heated under an air condenser at 100° C. for 70 minutes. The liquid mixture solidified on cooling. Water (150 cc.) and 6 N NaOH (15 cc.) were added and the solution extracted with ether to remove excess aniline. The aqueous layer was carefully neutralized with dilute HCl whereupon the product came down as a yellow precipitate. After drying, it weighed 3.2 g. (91 per cent.). Colorless plates melting at 145° C. (uncor.) were obtained on crystallization from water. They were insoluble in cold water and in petroleum ether, but soluble in ethanol, ether, benzene, dioxane, acids, and alkalies.

Analysis.—Calcd. for $C_{11}H_{10}O_2N_2S$: N, 11.96. Found: N, 11.97.

4'-Carbethoxy-3-pyridinesulfonanilide.—3-Pyridinesulfonyl chloride hydrochloride (4.28 g.) was added gradually with stirring to a solution of ethyl p-aminobenzoate (10 g.) in ether (50 cc.). The mixture was stirred for one hour and then allowed to stand for 12 hours. The precipitated benzocaine hydrochloride was filtered off and washed with ether. Evaporation of the combined ether filtrate and washings gave a residue which was leached with water (25 cc.) and then recrystallized from 50 per cent. ethanol (35 cc.) as colorless, irregular plates melting at 156° C. (uncor.). The yield was 5.28 g. (86 per cent.). The crystals were soluble in alcohol, ether, benzene, acids, and alkalies, but insoluble in water.

Analysis.—Calcd. for $C_{14}H_{14}O_4N_2S$: N, 9.15. Found: N, 9.23.

4'-Carboxy-3-pyridinesulfonanilide.—4'-Carbethoxy-3-pyridinesulfonanilide (4.3 g.) was dissolved in 6 N HCl (30 cc.) and the solution heated at 100° C. for 35 minutes. The mixture was cooled to 5° C. whereupon a crystalline precipitate (undoubtedly the hydrochloride of the desired product) formed. This was separated by filtration, washed with a small amount of cold 6 N HCl and dried. The yield amounted to 3.9 g. It was then dissolved in water (40 cc.) to which 2 N NaOH (15 cc.) had been added; a trace of insoluble material was filtered off and the desired product obtained by treating the filtrate with 2 N HCl until no more precipitate formed. The latter was filtered off, washed with water and dried. The yield was 3.3 g. (85 per cent.). The compound was recrystallized from 95 per cent. ethanol to give colorless micro prisms which melted at 241° C. (uncor.). They were soluble in acetone, hot ethanol, and dilute alkalies, but insoluble in water. They dissolved in 2 N HCl but slowly reprecipitated as needles (hydrochloride).

Analysis.—Calcd. for $C_{12}H_{10}O_4N_2S$: N, 10.07. Found: N, 10.31.

N-3-Pyridyl-3-pyridinesulfonamide.—3-Pyridinesulfonyl chloride hydrochloride (3.2 g.) was added gradually with stirring to a solution of

3-aminopyridine (4.3 g.) in ether (100 cc.) and allowed to stand for 5 hours. The ether was then decanted from the precipitate which had formed, and the latter washed with ether. The washed precipitate was then leached with water (120 cc.) and dried. An additional fraction precipitated on neutralizing the aqueous extract with dilute NaOH. The combined fractions were recrystallized from water (225 cc.), using Norite, to give colorless, micro prisms melting at 182° C. (uncor.). The yield was 2.16 g. (61 per cent.). The compound was soluble in ethanol, dilute acids, and dilute alkalies, but insoluble in cold water.

Analysis.—Calcd. for $C_{10}H_9O_2N_3S$: N, 17.86. Found: N, 18.00.

BOOK REVIEWS.

THE CHEMISTRY OF THE ALIPHATIC ORTHOESTERS, by Howard W. Post. 188 pages, tables, 16 × 23 cms. New York, Reinhold Publishing Corp., 1943. Price $4.00.

The purposes of the American Chemical Society Monographs, to which series this book belongs, are to present the knowledge of a topic in a form intelligible to those whose activities may be along a wholly different line, and to promote research in the branch of science covered, by furnishing a well-digested survey of the progress already made and by pointing out directions in which investigation needs to be extended. The subject of the orthoesters offers an interesting field for work.

In this monograph the subject matter is grouped under headings indicative of reactions rather than of compounds and under subheadings arranged in historical sequence. The work opens with a treatment on the preparation of orthoesters according to method. One of the most important of these covered is an adaptation of the Williamson synthesis of ethers, the so-called imidoester method, and the reaction of formic acid, its ester or amide, with a mercaptan in the presence of dry-hydrogen chloride to form a thio-orthoester. Orthoesters undergo many chemical reactions in which an inorganic acid or salt very definitely plays a catalytic role. This is made the subject of the next chapter and here it is assumed that ortho-ester-catalyst addition products are intermediate in most of the reactions under discussion, and the material is classified from this point of view.

Reactions with Organic Acids, Anhydrides and Halides is the heading of another chapter. The procedure is in this order. The interaction of orthoester and alcohol is dealt with last and phenol is grouped with the alcohols. Reactions with nitrogen compounds and organo-metallic compounds are next taken up. There are given several explanations of the peculiar properties of the esters of carbohydrates which are known to be different from those of a normal ester. These are in historical sequence. And then there are presented reactions which do not readily fall into the groups covered as for instance those due to the action of heat, or pyrolysis.

Orthoesters whose significant atom is silicon is the subject of the next chapter. Here the preparation and physical properties are discussed, and this is followed by a discussion of the reactions of these esters in aqueous media and other chemical properties. Following this there is a chapter on the compounds of elements of the fourth column of the Periodic Table other than carbon and silicon, in which the metal is connected directly to more than one alkoxyl group. Finally there is a list of physical properties of orthoesters.

The work fulfills the purposes of the American Chemical Society Monographs in every respect. It is a masterful and complete presentation of the present state of knowledge of the subject.

R. H. OPPERMANN.

BASIC ELECTRICITY FOR COMMUNICATIONS, by William H. Timbie. 603 pages, illustrations and diagrams, 15 × 22 cms. New York, John Wiley & Sons, Inc., 1943. Price $3.50.

The war has undoubtedly added much to the progress of electronics generally and radio communications in particular. Certainly there has been a great surge of interest in education along these lines. While much of this education has been in the armed forces, there was and still is considerable in private and public schools, as well as in home study. A number of text books have appeared intended to suit various situations. The present text is modeled after texts by the same author on practical electricity familiar to thousands of students. It reflects many years' experience in the educational field.

The course of study begins with a brief outline of the constitution of matter and the electron theory and proceeds through Ohm's Law, simple electric circuits, batteries, generators,

magnetism, properties of alternating current circuits, vacuum tubes and tube circuits, and electrical communication systems. The author squarely faces the fact that in any practical treatment of value a certain amount of mathematics is necessary in the solution of problems and to crystallize the theory in the mind of the student. This is in contrast to some of the recent texts. Another feature is the very useful problems for exercise. They appear wherever they are needed in the text and make it more impressionable and practical. The treatment is not too detailed but careful selection is made as to the depth of coverage. The book can be used in the classroom and in home study as well. It is of the grade that high school students may use.

R. H. OPPERMANN.

THE RISE OF THE PETROLEUM INDUSTRY, by Malcolm MacLaren. 225 pages, illustrations, 16 × 24 cms. New Jersey, Princeton University Press, 1943. Price $3.75.

Here is a story written by one who personally contacted many of the pioneers of the industry and who was in a position to observe many of the early developments. Malcolm MacLaren is an electrical engineer who graduated from Princeton in 1890. He has had considerable engineering experience both in this country and in England. He studied under Cyrus Fogg Brakett and for twenty-five years was chairman of the department of electrical engineers at Princeton University. In addition to his contributions and broad experience, the author has had the advantage of having available much of the apparatus of pioneers and developers, for Princeton was the scene of creative work by men such as Joseph Henry, Thomas A. Edison and Dr. Brakett.

The story of the electrical industry is told in this book in a non-technical fashion but facilities are provided to enable anyone who may so desire to make further study of any particular phase of the development. At the end of the book the reader will find a rather complete bibliography containing references to the principal papers bearing upon the subject. The method of presentation first lays out the early history of electricity, then takes up separately communication systems, illumination, motors and their application, direct current switchboards, direct current generators, precision instruments and methods of measurement, early alternating current developments, and commercial development of alternating current systems. Thus the presentation is an ordered one in comparison with a straight chronologic record regardless of arrangement of topics which has been the practice.

The work is authoritative and quite complete, filling in many gaps which heretofore have not been stressed.

R. H. OPPERMANN.

RADIO TROUBLESHOOTER'S HANDBOOK, by Alfred A. Ghirardi. 744 pages, illustrations, 22 × 29 cms. New York, Radio & Technical Publishing Co., 1943. Price $5.00.

It is estimated that there are some 55 million radio receivers in use in our country. Thousands of these are at the stage when they should normally be replaced. For the war's duration this is largely impossible and the service man is called upon to service this equipment, to repair many faulty parts which retain usefulness, to substitute and adapt the very limited variety and quantity of available replacement requirements. This demand on his ability and ingenuity requires complete fundamental knowledge of receiver circuits and design. Under this pressure it can be readily seen that a good, workable handbook is most valuable.

This book is in its third revised and enlarged edition. The previous edition in 1941 has been reviewed on these pages, but the book has undergone some changes made in the light of modernization and practicability. At the very beginning and for some 400 pages there are given case histories of actual trouble symptoms and remedies for the common troubles in 4820 models of various makes of home and auto-radio receivers and automatic record changers. These are arranged according to the name and type of set. Then attention is focused on intermediate transformer troubles and servicing and aligning superheterodyne receivers. The needs of the service man are visualized to an unusual extent as is evidenced by the very great quantity of information given. There is a cross index of model numbers, trouble shooter re-

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minder charts, gear ratios, scale calibration directions, interference and elimination data, replacement capacity values, battery data, resistance information, a tremendous amount of data on tubes of all kinds including transmitting tubes and cathode ray tubes, tube testers, circuit data, wire tables, logarithmic computations, and other mathematical means. When the size of the book and great quantity of data are observed the foremost question comes to mind, "Is it arranged so that it can be useful in the minimum of time?" The answer is "Yes." A stranger can find what he wants and, like all reference books, the more use it is put to, the greater the familiarity with its arrangement and contents.

R. H. OPPERMANN.

PRACTICAL PHYSICS, by Marsh W. White and Others. 365 pages, charts and diagrams, 16 × 23 cms. New York, McGraw-Hill Book Co., 1943. Price $2.50.

Not only under the present war conditions but, very probably, after actual fighting is over will there be increasing demand for men and women trained in basic physics. It is expected that post-war industrial developments will involve imprecedented application of physics in industry and will utilize the resources of men and women with knowledge of this science to a degree never before visualized. The Pennsylvania State College has recognized this fact and has caused this text to be prepared for use in adult education.

As the title of the book implies, it is practical and simple—built exactly for industrial training. Unlike many books of this type representing sources for industry, this book faces squarely the fact that if there is to be an effective use of the principles and measurements of physical science, there must be a workable knowledge of mathematics. The treatment accordingly makes use of mathematics as a tool. On the other hand, the mathematics required does not involve any of the higher branches and anyone familiar with mensuration and elements of algebra should have little difficulty. The method of presentation is good. Its order is, first, descriptive matter with worked-out examples as illustrations of formula application and substitution. Not too many derivations are made, and these only where necessary. Then a summary is given of the descriptive matter of each chapter, brief and pointed, with accent on brevity so that there is not enough to substitute for the text proper. After this, there is a list of questions and problems. Answers are given to a sufficient number of problems to maintain confidence. And at the end of each chapter experiments are laid out in complete form.

There are thirty-two chapters on as many subjects. Generally they cover measurements, heat, meteorology, mechanics, electricity and magnetism, communication, sound and light. An appendix gives numerous data as graphs, tables and equations. Of interest here is a brief treatment of the fundamentals of trigonometry for the solution of right triangles sufficient for anyone familiar with mensuration. There is also a table of logarithms for those able to use them. The subject index in the back adds to the value of the book for reference.

The book is good for home study as well as for classroom work for industrial worker students.

R. H. OPPERMANN.

ELECTRONIC CONTROL OF RESISTANCE WELDING, by George M. Chute. 389 pages, illustrations and diagrams, 16 × 23 cms. New York, McGraw-Hill Book Co., 1943. Price $4.00.

Electronic control of industrial processes is not new, although its field of application is so large that up to now the surface has hardly been scratched. Because of the great flexibility of electronic control it is practical in many applications not yet put to use. The installation of equipment to perform certain work and its performance is the spectacular side of the story. The maintenance and work in connection with keeping the equipment in running order is the practical side of the story. This is true with all control, including electronic control of resistance welding. At the present time, this very important work is often entrusted to mechanics not too familiar with electrical systems and electronics. It is with the purpose of educating these mechanics that the book at hand is written.

The book is an outgrowth of a course of lectures given by the author to workers in the Detroit area. It is written in plain, simple language, requiring only the background of the average maintenance worker for understanding. There are three parts to the book, the first dealing with Ignitron Contactors, Tubes and Weld Timers. Here, after a brief treatment on the resistance welder and some principles of alternating current for the welder, a description is given of the ignitron contactor, its installation and operation. Information is given about the tubes and tube checking, as well as the time delay relay. The thyratron tube is also given attention, as are various aspects of welding generally including trouble shooting.

Part Two is devoted to Synchronous Control of A-C Welding. This starts with connections and elementary diagrams and proceeds through the topics of the synchronous timing circuit, the spot-welding timer including heat control, starting and maintaining the synchronous panel, locating trouble, control for seam, spot and pulsation welding, and a discussion on welder controls used with series capacitors. Energy-storage Welding is the heading of Part Three of the book. After an explanation of welding with stored energy, there are taken up capacitor storage, reactor storage, and a description of General Electric stored energy welding control including how the rectifier tubes are grid-controlled so as to start the charging operation gradually, or so as to obtain quickly a trickle charge of the capacitors.

To the serious minded mechanic, this book offers a means to understanding a very important piece of apparatus. In accord with its purpose there is little mathematics treatment. It can therefore be used by anyone with a limited knowledge of electricity. For classroom use it is excellent.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

The Chemical Background for Engine Research, by R. E. Burk and Oliver Grummitt. 297 pages, charts and diagrams, 15 × 23 cms. New York, Interscience Publishers, Inc., 1943. Price $3.50.

Metals and Alloys Data Book, by Samuel L. Hoyt. 334 pages, tables, 18 × 26 cms. New York, Reinhold Publishing Corp., 1943. Price $4.75.

Alternating Current Circuits, by Russell M. Kerchner, M.S., and George F. Corcoran, M.S. 553 pages, charts and diagrams, 14 × 22 cms. New York, John Wiley & Sons, Inc., 1943. Price $4.75.

Drying and Dehydration of Foods, by Harry W. Von Loesecke. 302 pages, illustrations, 16 × 23 cms. New York, Reinhold Publishing Corp., 1943. Price $4.25.

CURRENT TOPICS.

Birth of a New Volcano, in Michoacán, Mexico.—EZEQUIEL ORDONEZ, Mining Geologist and Engineer, and Honorary Member, AIME, gives a vivid description of a very unusual sight in *Mining and Metallurgy*, Vol. 24, No. 439. On an afternoon of last February a new volcano was born in the center of the State of Michoacán, Mexico, about 100 miles inland from the Pacific Coast. Creation of this new mountain forming crater began on an almost flat cultivated field at the south margin of a small basin about a mile in diameter and having an altitude of approximately 6,800 ft. above sea level. This basin is connected to a gently inclined plain that forms the Parangaricutiro valley, the chief town of this municipality, bearing the same name as the valley, being situated three miles from the site of the new crater. The village of Paracutin, from which the new volcano received its name, is about one mile to the northwest of the crater. From the City of Mexico to the volcano is a distance of 330 miles. Fifteen days before the eruption of the Paracutin volcano, repeated earthquakes were felt within a limited area close to the present site of the crater. These disturbances caused great alarm among the inhabitants of the vicinity. The owner of the land on which the new volcano was born indicates that he felt repeated shocks accompanied by deep underground rumblings. In the late afternoon he saw small columns of smoke rising from a small depression in the middle of one of his plowed fields, and these soon began to increase in size and intensity. Within a short time flames were coming with the smoke and large pieces of rock and dust were being thrown into the air. At the sight of this terrific manifestation of natural forces, the native farmer was thrown into a panic and he ran all the way to the town of Paracutin and from there he went to Parangaricutiro to inform the authorities of the fact that a great catastrophe was happening on his lands. By nighttime the explosions of the volcano were felt in these small towns and the great glow from the flames of the crater had completely terrorized the inhabitants. Early next day many people from nearby settlements came to the place to see what was happening and to their astonishment they saw that the young volcano had already thrown up a mound nearly 100 ft. high and that its crater was steadily growing in size by the piling up on its sides of incandescent rocks and dark sand that were coming from within the earth. At the same time an enormous column of vapors and smoke was rising into the air to an inconceivable height.

R. H. O.

Ford Reclaims Tungsten Carbide Chips.—(*Iron Age*, Vol. 152, No. 3.) A process is now being used in the Aircraft Engine Division of Ford Motor Co. to recover or reclaim tungsten carbide tool tips that have chipped so badly as to be nonusable by regrinding. The first step is the removal of the carbide tip from its steel shank. This is accomplished by keeping the tool for 1 hour in a concentrated bath of nitric acid at a temperature of about 150 deg. F. It is then removed from the acid bath and washed in water, and a slight tap

then will loosen the carbide chip. Next the chips are washed in a bath of ammonium hydroxide, after which they are tumbled in a ball mill to clean them. Titanium and tantalum carbide chips must be removed since they are not recoverable by the present method of resintering. This is accomplished by passing the chips through a hydrogen atmosphere furnace at 1650 deg. F., in which the titanium and tantalum carbide chips acquire a brownish color, while the tungsten carbide tips retain their light gray color, so that the former can be readily recognized and separated out. While still in the hydrogen atmosphere, the chips are pushed into a cooling zone for 2 to 3 min. where the temperature is allowed to drop to about 1000 deg. This limits the amount of oxidization that might take place upon withdrawal. After visual grading and separation the chips are passed through a modified mercury flotation process in order to assure final separation of the titanium and tantalum grades which are lighter than the tungsten grades and float on the mercury. The carbide chips are next pulverized in a 100 lb. Bradley power hammer, which operates at approximately 250 strokes per min. A hardened steel mortar and a pestle are used on this hammer. The pestle reciprocates through a packing gland that prevents the escape of carbide dust. The carbide is fed into the mortar through an iron standpipe, and the pulverized product is drawn off by the air current of a centrifugal exhauster, through a cloth filter. The dust settles in a trap from which it is recovered. The pulverized tungsten carbide is now put into carbon boats and placed in a hydrogen atmosphere furnace at 1500 deg. for 20 min. to reduce any oxides that may be present. The powder is then put through a 400-mesh sieve, and the portion that passes through is ready for further use. The part that does not pass through is fed back into the power hammer and repulverized. A binder consisting of a 3½ per cent. solution paraffin wax in trichlorethylene is added to the powdered carbide, and this mixture is dried in an oven at 140 deg. for approximately 2 hours. It is now ready for forming into shapes. From this point on, the process is similar to that used in the manufacture of new carbide tips from powder.

R. H. O.

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Parachutes in Tropics Protected by Air Conditioning.—(*Heating and Ventilating*, Vol. 40, No. 7.) One of the many vital war roles being performed by modern air conditioning is the drying and storage of parachutes, illustrated by the drying equipment installed recently by Carrier in a parachute drying tower located in the Republic of Panama. Parachutists in training at the air base frequently land in marshy or swampy terrain or even in the sea and it is imperative that their parachutes be immediately washed and dried to prevent deterioration. The drying tower consists of two sections. In one, 30,000 cfm of heated air and 100,000 cfm of outside air enter through nozzles on the ceiling and blow vertically downward over the 'chutes which are suspended from the ceiling. The air is exhausted at floor level. After most of the free moisture (up to 25 per cent. by weight) is removed, the 'chutes are taken down and hung in the other and much larger section where the moisture content is brought to the correct value. They are then removed to large air-conditioned rooms for folding, packing and storage. Three Carrier heat diffusers supply heated air to the two sections of the drying tower, while self-contained air conditioning units supply 50 tons of cooling effect for air con-

ditioning for the folding, packing and storage rooms and for offices. Most parachute maintenance buildings have a tower approximately 40 ft. high where the parachutes are hung and fluffed out following the routine of 30- or 60-day inspection before repacking. It is important that the relative humidity within a drying tower be kept below 50 per cent. and that outside air be circulated through the tower to prevent mildew, which damages silk fabric. This may be accomplished either by using a dehumidifying unit comprising a compressor, evaporator and hot gas reheat coil with fans for air circulation or by using a heat diffusing unit. In some parachute maintenance buildings bins are provided for storing packed parachutes. This section is partitioned off from the rest of the shop and equipment is provided to keep the space ventilated and the humidity below 50 per cent. In some tropical work rooms, complete air conditioning has been installed to prevent dust and excessive sweating of parachute riggers, thus preventing perspiration from dripping on the 'chutes while they are being folded. In such cases, 80F DB and 50 per cent. RH are provided.

R. H. O.

Beyond the Red.—(*Industrial Bulletin of Arthur D. Little, Inc.*, No. 191.) With infrared spectroscopy, infrared rays are used to determine the nature and characteristics of materials, just as visible rays are used in the ordinary spectroscope, and with valuable results both in scientific investigation and manufacturing control. Infrared spectroscopy is analogous to visible spectroscopy except that because of the opacity of glass to infrared light, prisms of rock salt and potassium bromide must be used and the usual lenses must be replaced by mirrors. Moreover, the presence or absence of a particular wave-length must be detected by a delicate temperature-measuring device, known as a thermopile, rather than by the eye or by a photographic plate. An index of the infrared spectra of a large number of common chemicals was published by William W. Coblentz in 1905–6, but the technique did not come into industrial use until the middle thirties with the development of quick automatic spectrum recording, and only recent war requirements have pushed it into the foreground. Infrared spectroscopy is useful whether the material studied is colored or not; many colorless materials, including most of those used in synthetic rubber manufacture, do not absorb any visible light at all and hence cannot be identified by visible spectroscopy. These materials do, however, absorb characteristic portions of the infrared spectrum, and infrared spectroscopy thus proves useful in controlling the manufacture of synthetic rubber and its raw materials. Infrared spectroscopy is particularly useful in dealing with petroleum derivatives, many of which are colorless, and is used for the most part in studying the molecular structure and composition of organic substances rather than of inorganic materials. During the past decade it has become possible to determine many of the properties of materials simply by calculation from data obtained spectroscopically, and some of these data must be obtained from the infrared spectrum. This determination of physical properties from a few fundamental spectroscopic measurements holds great promise for the future and is at present one of the most actively developing fields of science.

R. H. O.

Barge Places 90-Ton Breakwater Blocks.—C. H. CRUTTWELL. (*Engineering News Record*, Vol. 131, No. 3.) A dumping barge of unusual design and construction was used to transport and place 90-ton concrete blocks in a breakwater recently completed at the port of Leixoes, Portugal. The job involved extending an existing breakwater about 3,300 ft., of which the first 1,300 ft. was a coursed wall built of heavy rectangular concrete blocks, while the remaining 2,000 ft., subject to considerable wave action, was a submerged-mound type of granite rubble base capped by the 90-ton concrete blocks. It was for construction of this outer end of the breakwater that the special barge was required. The special feature of the barge, which was 141 ft. long overall, with a 32-ft. overhang at the bow, permitted a close approach to the breakwater when dumping the blocks. Designed as a heavy beam, the central portion of the barge supported a track of two pairs of railroad rails carrying a tipping car. This beam and track arrangement was at the bottom of a trough extending nearly the full length of the hull. A seven-ton steam-powered winch in the stern of the barge propelled the tipping car through four $1\frac{1}{4}$ in. steel cables. Two water-ballast tanks, placed aft, could be filled or emptied as required to control the inclination of the deck under different loadings. Mounted in the bow of the barge were five cast steel rollers over which the concrete blocks were tipped. The 90-ton cubical concrete blocks were loaded in line along the center of the barge, resting on hardwood battens bolted longitudinally along each side of the trough. Seven blocks, 12 ft. $3\frac{1}{2}$ in. $\times$ 10 ft. 8 in. $\times$ 10 ft. 10 in., constituted a barge load. After loading, the barge was towed to the breakwater site and made fast to six buoys by 7-in. coir rope cables and the car was hauled forward causing the block to roll over the bow rollers and, once the center of gravity had passed the equilibrium point, the block tipped over.

R. H. O.

Wooden Barrel Buoys Prove Superior.—(*The Wooden Barrel*, Vol. XI, No. 11.) About seventy charred oak whiskey casks now are being converted into channel-marking buoys by the Coast Guard as a first step in an inclusive program to save precious steel and over-all cost, by substituting the barrels for metal drums now in use. Although other types will be utilized in making buoys, the whiskey barrel will probably be in the majority, Coast Guard officials explained, since distillers can use them only once. Hence they are more plentiful. One of the new type "barrel" buoys already is in use marking the Mississippi River channel in the fast water at Chain of Rocks, opposite North St. Louis. Under trying conditions, it is meeting all expectations, Lieut. Commander R. M. Freeman, aide to navigation officer, reported. Not only will these new buoys effect a great saving of steel and production cost, but preliminary tests showed they have a number of definite advantages over the metal buoys. These tests proved that the barrel buoys can be seen by pilots more than twice as far away as the metal ones, said R. R. Kirsch, research engineer at Coast Guard district headquarters, St. Louis, who developed the idea. In one of the Coast Guard's sixteen districts, more than 8,000 buoys and lights are used, safeguarding over 6,500 miles of inland waterways. The Mississippi River and all of its tributaries are carrying the highest tonnage in history. With the barrels ballasted by concrete in the bottoms and with the

metal cone or can marking designation fitted to their tops, the barrel buoys were anchored in the same manner as the metal drums, but their action in the water was exactly opposite. Instead of inclining downstream they leaned upstream, causing a lifting action against the current that carried them higher out of the water. These new buoys will have the further advantage of ease in handling and stowage on Coast Guard buoy tenders. Three barrels can be stacked in the space of one metal buoy. The metal tops, which are interchangeable, can be nested until ready for use. They will also eliminate the necessity of carrying two separate types of buoys used to mark the right and left side of the channel.

R. H. O.

Ship Tonnage Defined.—(Editorial by R.G.S. in *Compressed Air Magazine*, Vol. 48, No. 7.) Pat, the hod carrier, was sent by his boss to measure a short stretch of wall. And for that purpose he was given a folding foot rule. When Pat came back and was queried: "Did you get it?" Pat answered: "Shure, Sor. It was double the lingth o' the rule, half agin the lingth o' me arm, and as long as this shtick and this piece o' shtring." The ways of measuring a ship are as diversified as Pat's procedure. In the case of a Liberty Ship, for example, the term tonnage is applied variously, and each has its own significance. There is displacement tonnage, dead-weight tonnage, cargo-capacity tonnage, gross tonnage, and net tonnage. These are confusing to most people, and yet, with their wide differences in numerical value, they may be applied to the same vessel. A ship in any state of lading floats because it has actually displaced an equal weight of sustaining water. Therefore the naval architect uses displacement tonnage as his basic yardstick of measurement. Each ton of sea water displaced represents 35 cubic feet, and each cubic foot weights 64 pounds—the displacement ton being the same as the familiar long ton of 2,240 pounds. A vessel's displacement may range from her lightest condition afloat to her deepest draft when laden to the permissible maximum. Displacement light is her weight excluding cargo, passengers, fuel, water, stores, etc., when being made ready to go to sea. Displacement loaded is the total weight, including cargo, passengers, fuel, water, stores, etc., aboard when about to leave port. Dead-weight tonnage, also measured in tons of 2,240 pounds, is the difference between displacement loaded and displacement light, and is the carrying capacity of a craft. The cargo-capacity tonnage is the number of tons left after the weight of the fuel, water, stores, and other items necessary for use on a voyage has been deducted from the dead-weight tonnage. Gross tonnage, which is expressed in tons of 100 cubic feet, is the entire internal cubic capacity of a vessel—in short, just space, of which a considerable percentage is not available for use. On the other hand, net tonnage represents "earning space"—the space remaining after certain deductions have been made from the gross tonnage to provide accommodations for the crew and room for propelling machinery, etc.

R. H. O.

The Royal Electrical and Mechanical Engineers.—From daily observations of news from the war theater, it becomes increasingly plain that modern warfare is greatly dependent upon the machine. And not only does it depend

on the design of the machine and its ability to do its work properly and efficiently, but on the availability of the machine, that is to say its maintenance and condition for service. In this connection it is interesting to note the development in the British Army of a new Corps—The Royal Electrical and Mechanical Engineers. This Corps was formed under authority of a Royal Warrant to meet a long felt want in the British Army to conserve the technical man power and to coördinate electrical and mechanical military engineering in one Corps, as a separate entity. The function of the Corps is (1) inspection and maintenance of tanks, wheeled vehicles, all artillery (including field anti-aircraft, and coast defense), small arms and machine guns, radiolocation, fire control, and all other instruments, tunneling equipment, pumping sets, and the installation of coast artillery machinery; (2) repair of all the above equipments consequent upon ordinary wear and tear, or battle casualties; (3) investigation into defects of design and recommendations for improvements; (4) advice on prototype design from a maintenance angle. There is a complete chain for the direction and coördination of the technical activities of the R.E.M.E., as the Corps is designated, starting with the Director of Mechanical Engineering in the War Office, Major-General E. B. Rowcroft, C.B.E., M. I. Mech. E., and passing down through Deputy Directors to the Electrical and Mechanical Engineer or E.M.E. as he is called, who acts as technical adviser to a Brigade Commander. Each formation—Army, Corps, Division—and certain individual units have their own mobile workshops and engineering staff. Much effort is directed by R.E.M.E. to obtain mechanic recruits of various kinds, as well as students and graduate engineers.

R. H. O.

Large 3,600 R.P.M. Turbo-Generator Is Now in Operation at Los Angeles.—(*Industry and Power*, August 1943.) Described as the largest unit of its type ever built, a turbo-generator producing 65,000 kw. of electricity has just gone into operation for the Bureau of Power and Light at Los Angeles Harbor.

Steam at 850 lb. and 900° F. is employed and the shaft of the turbine turns at 3,600 r.p.m. At peak speed, the tips of the blades on the shaft, having a maximum diameter of about 6½ ft., travel at the approximate rate of 850 miles per hr.—about 100 miles an hour faster than the speed of sound.

Built by Westinghouse the new machine can produce enough electrical energy to light more than 1,000,000 standard 75-watt incandescent Mazda lamps simultaneously.

Fractional horsepower motors adjust the steam flow and governor controls which regulate load through valves. Generator, bearing and generator gas temperatures, voltage output, shaft rotating speed, frequency and electrical load conditions are all recorded on graphic meters at the control house and on the supervisory board in the turbine room. These control and assist the mechanically precise equipment to operate over a wide range of load with high electrical stability.

Electro-magnetic devices watch for potential trouble in the rotating part of the huge machine—a 43-ton piece about 65 ft. long—by constantly measuring vibration, heat expansion, and eccentricity. As an added precaution, small temperature detectors are imbedded in the armature winding of the generator to record any tendencies to overheat electrically.

In the event of earthquake disturbances, the shaft and other rotating and stationary parts will withstand horizontal forces without getting out of alignment.

High heat developed in the generator from rotational losses is dissipated by hydrogen gas, which is passed at the rate of 400,000 lb. an hour through the coolers built around the generator. The cooler has a capacity of 63,000 cu. ft. of hydrogen per minute.

P.

Increasing the Fatigue Strength of Machine Parts.—(*Machinery*, Vol. 63, No. 1609.) Impressive increase of fatigue strength by pre-stressing in compression a thin layer of a machine part has been established as a reliable practice for a considerable time. The pre-stressing may be done by peen hammering, swaging, shot blasting, or by pressure operations by balls or rollers. It is the newly improved technique in this, and the extension of it, that has recently aroused the attention of the industry. It is through the introduction of new concepts of fatigue phenomena that the significance of these useful processes have recently become clear, and by which new avenues of reasoning and development have been opened. These new concepts are: (1) Fatigue failures result only from tensile stresses; (2) never arise from compressive stresses; (3) any surface, even finely finished, is a stress-raiser.

The metallurgist knows that surfaces of repeatedly stressed components, even perfectly finished, are more vulnerable than the deeper layers. It has been long known that fatigue liability increases with surface roughness, especially if this consists of notches perpendicular to the main stress. But it has been appreciated only recently that specimens with super-finished surfaces do not best withstand fatigue. There is an extra fatigue risk in the surface layer—simply because it is a surface—not shared with the deeper layers. However carefully prepared may be the specimen, its fatigue strength will be considerably increased if a thin surface layer is pre-stressed by any of the methods already mentioned. A theory that has probability is that surface compression is effective because, when the load is applied, surface tension stress is less by the amount of the compression stress; and since fatigue failure starts from tension stress, the fatigue endurance of the weak surface layer is increased. While the tension in the lower layers is not less and may be more, the fatigue strength of the whole is improved. It follows therefore that the lower layer is inherently stronger than the surface one.

P.

Oscillographic Records of Foot and Muscle Action Aid in Treating Infantile Paralysis and War Victims.—Treatment of infantile paralysis victims, industrial and war cripples may be improved through data recorded by a twelve element oscillograph developed in the Myodynamics Laboratory of the University of Rochester School of Medicine. Capable of recording all factors essential for the study of foot function while walking, this instrument is the result of 17 years of research conducted under the direction of R. Plato Schwartz, M.D., head of the division of Orthopedics. Resistance disks are applied to six points on the bottom of each foot. Each disk is smaller, and slightly thicker than a dime, so that records may be made either barefoot or

with the subject wearing various types of footwear. The current passed by each of these disks varies in proportion to the pressure exerted upon it as the patient walks. By means of a suitable cable each disc is connected to one of the 12 high sensitivity General Electric galvanometer elements. A tiny mirror in each galvanometer reflects a pin point light beam as the galvanometers deflect in response to pressure changes on respective disks. Focussed through an optical system, these beams strike a strip of photographic paper eight inches wide, 200 ft. long, which is moved past a slit aperture at constant speed by a synchronous motor. Since the light beams swing at right angles to the direction of paper travel, twelve curves are produced revealing the function of six areas on each foot. These curves reveal the duration, amount and sequence of simultaneous pressure changes with 95% accuracy. The oscillograph was designed and built in the Myodynamics Laboratory by Arthur L. Heath, Research Associate, with assistance from General Electric engineers. Analysis of nearly 4000 normal and pathologic records has resulted in the formulation of standard time and pressure values for normal walking. Comparison of values derived from records of patients under treatment with the norms provides a positive check on the effectiveness of therapy. These procedures are applicable in any disease affecting the patient's ability to walk. Changes in foot function resulting from differences in heel height have been recorded. Differences in function resulting from other factors in shoe construction and design are also subject to precise measurement. More recently the scope of usefulness of the oscillograph has been widened by its application to the recording of Muscle Action current curves. For this purpose four high gain amplifiers were constructed by Dr. H. D. Bouman and matched to the General Electric galvanometer elements. Records of this type are of major importance to the study of infantile paralysis and other forms of neuromuscular pathology. Such records make it possible to demonstrate the presence of spasm in muscles formerly considered to be unaffected by the disease, infantile paralysis.

R. H. O.

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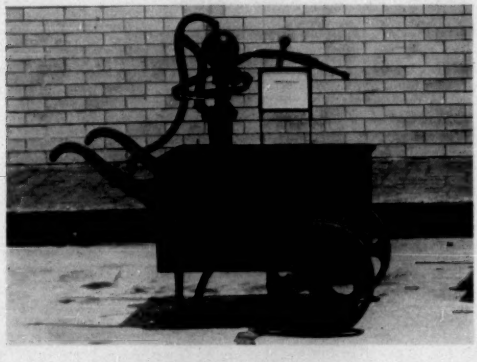

RUBBER HOSE—
STRONGER THAN THE ENGINE ITSELF

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In May, 1827, the Franklin Journal said that the introduction of rivetted leather hose was perhaps the most important improvement yet made in the means for extinguishing fires.

But ten years later the Journal for June, 1837, reported a competitive test made in London, England, which proved the superiority of India Rubber hose. A length of leather and India Rubber hose were each attached to the "powerful" floating engine of the London Assurance Co., each "furnished with a branch tightly corked." On starting the engine the leather hose soon burst from the accumulated pressure. The rubber hose did not only hold, but it disabled the engine, breaking a crank when the pressure built up.

The superiority of rubber as proved in 1837 is today manifested many times over in Republic Rubber hose, belting and other mechanical rubber products—and in tires by LEE of Conshohocken.

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